WIND SHEAR DETECTION TECHNOLOGY

HEARING

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND MATERIALS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-EIGHTH CONGRESS

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JULY 25, 1984

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WIND SHEAR DETECTION TECHNOLOGY

WEDNESDAY, JULY 25, 1984

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON TRANSPORTATION,
AVIATION, AND MATERIALS,
Washington, DC.

The subcommittee met, pursuant to notice, at 9:38 a.m., in room 2318, Rayburn House Office Building, Hon. Dan Glickman (chairman of the subcommittee) presiding.

Present: Representatives Glickman, Gore, Carney, and McCandless.

Also present: Representative Walgren.

Mr. GLICKMAN. Good morning.

Today the subcommittee focuses its attention on a very important issue involving the flying public. That is the issue of wind shear and how that concept affects airliners and airplanes flying near airports, landing and taking off, particularly during thunderstorms but perhaps in otherwise bad weather. Our understanding of wind shear, although limited, has progressed in recent years. In spite of this progress, however, low-altitude wind shear continues to be a significant hazard to aviation. Thus, our objective to examine our current technical capability to detect wind shear, the status of the FAA's low-level wind shear alert system implementation program, as well as the operational aspects of assuring that pilots have timely and accurate weather information en route, and especially on takeoff and landing.

Wind shear is, fortunately, a relatively infrequent hazard. When it does occur, however, it can have catastrophic results. Wind shear, which is particularly deadly during takeoff and landing, has downed at least seven airliners in the last decade, including the Pan Am 727 which crashed shortly after takeoff from New Orleans on July 8, 1982, killing all 145 persons on board and 8 others on the ground. Just last month, a USAir DC-9 was forced to the ground by wind shear as the pilot was retracting the landing gear to make another pass at Detroit Metropolitan Airport.

I am particularly concerned about reports that pilots often do not have timely and accurate severe weather information. For example, I understand that the USAir pilot may not have been specifically advised of the wind shear alert at Detroit last month, and did not make a request for clarification of the information that was being received. In addition, many pilots indicate that the wind shear alerts occur so often that sometimes they are discounted or perhaps even ignored. Specifically in the case of the USAir situa-

tion, the pilot—at least in a newspaper article—indicated that the ground was so busy with traffic conditions during a thunderstorm that he could not even understand the kind of information coming from the ground as it related to weather information.

Beyond the issue of the communication of wind shear alerts, I am concerned that the FAA is not taking advantage of the National Weather Service radar weather data. That information clearly should be made available to control towers so that the controllers can provide the latest severe weather information to pilots prior to departure or landing. Again, this has been something that has concerned me for a long time. We have great weather information en route. Pilots can skirt around thunderstorms with no problems at all when they're at 33,000 feet, but what happens on the ground when the controllers are directing lots of traffic and are perhaps either less concerned about weather than they are about traffic or don't know what's happening outside their control tower. That's where a bulk of weather accidents occur, and there is a gap there that does not seem to be cured by any of the modern technology that we have in place right now.

So, beyond the question of technology, we need to assure that the operational and procedural aspects of the problem are addressed.

Now I would like to turn, for his comments, to my ranking Member, Mr. Carney from New York.

[The opening statement of Mr. Glickman follows:]

OPENING STATEMENT

HONORABLE DAN GLICKMAN, CHAIRMAN
SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS
COMMITTEE ON SCIENCE AND TECHNOLOGY
U. S. HOUSE OF REPRESENTATIVES

HEARING: WIND SHEAR DETECTION TECHNOLOGY

JULY 25, 1984

TODAY THE SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS WILL FOCUS ITS ATTENTION ON WIND SHEAR DETECTION TECHNOLOGY. OUR UNDERSTANDING OF WIND SHEAR, ALTHOUGH LIMITED, HAS PROGRESSED IN RECENT YEARS. IN SPITE OF THIS PROGRESS, HOWEVER, LOW-ALTITUDE WIND SHEAR CONTINUES TO BE A SIGNIFICANT HAZARD TO AVIATION. THUS, OUR OBJECTIVE IS TO EXAMINE OUR CURRENT TECHNICAL CAPABILITY TO DETECT WIND SHEAR, THE STATUS OF THE FAA'S LOW-LEVEL WIND SHEAR ALERT SYSTEM IMPLEMENTATION PROGRAM, AS WELL AS THE OPERATIONAL ASPECTS OF ASSURING THAT PILOTS HAVE TIMELY AND ACCURATE WEATHER INFORMATION EN ROUTE, AND ESPECIALLY ON TAKE OFF AND LANDING.

WIND SHEAR IS, FORTUNATELY, A RELATIVELY INFREQUENT HAZARD. WHEN IT DOES OCCUR, HOWEVER, IT CAN HAVE CATASTROPHIC RESULTS. WIND SHEAR, WHICH IS PARTICULARLY DEADLY DURING TAKE OFF AND LANDING, HAS DOWNED AT LEAST SEVEN AIRLINERS IN THE LAST DECADE, INCLUDING THE PAN AM 727 WHICH CRASHED SHORTLY AFTER TAKE OFF FROM NEW ORLEANS ON JULY 8, 1982, KILLING ALL 145 PERSONS ON BOARD AND EIGHT OTHERS ON THE GROUND. JUST LAST MONTH, A USAIR DC-9 WAS FORCED TO THE GROUND BY WIND SHEAR AS THE PILOT WAS RETRACTING THE LANDING GEAR TO MAKE ANOTHER PASS AT THE DETROIT AIRPORT.

I AM PARTICULARLY CONCERNED ABOUT REPORTS THAT PILOTS OFTEN DO NOT HAVE TIMELY AND ACCURATE SEVERE WEATHER INFORMATION. FOR EXAMPLE, I UNDERSTAND THAT THE USAIR PILOT MAY NOT HAVE BEEN SPCIFICALLY ADVISED OF THE WIND SHEAR ALERT AT DETROIT LAST MONTH, AND DID NOT MAKE A REQUEST FOR CLARIFICATION OF THE INFORMATION THAT WAS BEING RECEIVED. IN ADDITION, MANY PILOTS INDICATE THAT THE WIND SHEAR ALERTS OCCUR SO OFTEN THAT THEY ARE SOMETIMES DISCOUNTED OR PERHAPS EVEN IGNORED.

BEYOND THE ISSUE OF THE COMMUNICATION OF WIND SHEAR ALERTS, I AM CONCERNED THAT THE FAA IS NOT TAKING ADVANTAGE OF NATIONAL WEATHER SERVICE RADAR WEATHER DATA. THAT INFORMATION CLEARLY SHOULD BE MADE AVAILABLE TO CONTROL TOWERS SO THAT CONTROLLERS CAN PROVIDE THE LATEST SEVERE WEATHER INFORMATION TO PILOTS PRIOR TO DEPARTURE OR LANDING.

SO BEYOND THE QUESTION OF TECHNOLOGY, WE NEED TO ASSURE THAT THE OPERATIONAL AND PROCEDURAL ASPECTS OF THE PROBLEM ARE ADDRESSED.

I LOOK FORWARD TO A VERY PRODUCTION HEARING AND WELCOME THE WITNESSES WHO HAVE AGREED TO ASSIST US TODAY.

Mr. CARNEY. Thank you, Mr. Chairman.

Two years ago 153 people were killed when a Pan American 727 jet airliner encountered wind shear at the New Orleans International Airport and, as a result of that tragic accident, a committee was established to study low-altitude wind shear and its hazards to aviation.

The problem of wind shear has been the subject of considerable study for more than a decade. The FAA, in cooperation with the National Weather Service, the National Science Foundation, and NASA, has conducted a number of programs to investigate the nature and cause of wind shear. The JAWS program, which was conducted 2 years ago at the Stapleton Airport in Denver, CO, provided a wealth of meteorological data. In addition, simulator studies have been conducted to determine the appropriate operational procedures in the presence of wind shear. Significant resources have also gone into the development and detection and prediction systems—both airborne and ground-based installations, yet the recent USAir DC-9 incident at Detroit is a reminder that the problem is still with us.

The Pan Am accident 2 years ago occurred in spite of the installation of a low-level wind shear alert system. The Detroit Metropolitan Airport also has such a system in operation. Moreover, the USAir accident occurred during a severe thunderstorm—a condition known to produce hazardous low-altitude wind shear. Why are these warnings being ignored?

Do we need more research on the nature of wind shear, or should we now be concentrating our resources on more accurate and believable detection systems? Perhaps we should be directing some of these resources to the development of augmented guidance and control systems for flying through wind shears, or simulator studies for developing improved piloting techniques for coping with wind shear encounters.

Wind shear encounters may be infrequent, but they continue to pose serious hazards to aviation. I thank you, Mr. Chairman, for giving us the opportunity to address these issues with the distinguished witnesses who are here today.

I yield back the balance of my time.

Mr. GLICKMAN. Mr. McCandless, do you have any comments?

Mr. MCCANDLESS. Thank you, Mr. Chairman. Not at this time.

Mr. GLICKMAN. OK. Our first witness is our friend Jim Burnett, Chairman of the Safety Board. We are pleased that you are here, Jim. Why don't you go ahead and begin? You're always one of our favorite witnesses because you speak very, very clearly to the issues, and this is an issue that I think is capable of some solution. At least the technology seems to be moving in that direction, and we hope that your testimony will amplify our views and our understanding of it.

STATEMENT OF JIM BURNETT, CHAIRMAN, NATIONAL TRANSPORTATION SAFETY BOARD, ACCOMPANIED BY WILLIAM LAYNOR, DEPUTY DIRECTOR, BUREAU OF TECHNOLOGY; AND GREG SALOTTOLO, METEOROLOGIST

Mr. BURNETT. Mr. Chairman, I am pleased to have the opportunity to appear before you today to discuss the subject of wind shear detection technology. I would like to introduce the members of the Safety Board staff here with me. On my left is Mr. William Laynor, who is the Deputy Director of our Bureau of Technology and one of our foremost experts on wind shear detection technology; and on my right Mr. Greg Salottolo, who is a Safety Board meteorologist.

While testifying recently before another congressional committee, I was asked what I thought is the greatest threat to aviation safety, and my reply was—weather. Since the beginning of aviation, weather has always been the one factor over which we have no control. We can only minimize its impact by learning more about it and avoiding the worst of it.

Much work has been done with regard to wind shear, but recent incidents bring home the point that there is still a great deal left to be accomplished. For example, less than 6 weeks ago a USAir DC–9 carrying 50 passengers and 5 crew members crashed while attempting a go-around following its approach to Detroit's metro airport. It appears they flew into what is referred to as wind shear. The flightcrew began the approach at the time a heavy rainstorm was over the airport and the tower controller was announcing significant low-level wind shear readings.

The chairman is quite right that, although these readings were given to the tower, they were not stated in terms explictly of being a warning, although we think perhaps they should have been recognized for that. Fortunately, only minor injuries resulted.

Testifying before the Safety Board last week at a deposition proceeding in Detroit, the USAir pilot provided a dramatic account of his efforts first to fly through the wind shear and then his resignation in calling for the landing gear as his airplane literally fell out of the sky.

Less than 2 weeks prior to the Detroit wind shear encounter, a United Airlines 727 struck a localizer antenna after taking off from the Denver Stapleton Airport in what turned out to be wind shear. In this case, too, there were low-level wind shear alerts and other indications which might have prompted a decision to delay takeoff. Fortunately, the crew was able to avoid a disaster because of its training to use all of the airplane's performance capabilities in a wind shear encounter. There were no injuries in this instance, either.

Wind shear has always been with us, although it is interesting to note that it has only been during the past decade that the aviation safety community has acknowledged wind shear per se as a serious aviation problem. While the conditions are rare which can produce a level of shear sufficient to override normal airplane performance—I might want to amend that. Wind shear is very common. However, it is relatively rare when you have it occurring at a point where an air transport category aircraft is at low altitudes where it becomes critical and at a strength that would prohibit the aircraft

flying through it. We at the Safety Board believe that wind shear is probably a greater threat to airplanes now than it was 20 years ago.

One reason for this is the growth in the number of flight operations. Although wind shear does occur in otherwise relatively good weather, the most severe flight hazard is generally produced by the convective winds which are often accompanied by thunderstorms or heavy rain showers—although they need not be—the type of weather that generally used to keep airplanes on the ground. Advancements in both ground-based and airborne navigational guidance and control systems undoubtedly have contributed to more frequent flight into this type of weather condition.

Another possible reason concerns the evolutionary changes in airplane design. Each new generation of airplanes has brought advances in performance—defined by speed, range, payload, and specific fuel consumption. It does not necessarily follow, however, that the pilot of a modern high-performance airplane can cope with a wind-shear encounter any better or even as well as the pilot of a straight-wing, propeller-driven airplane. In fact, an analysis of airplane performance indicates that a swept-wing turbojet airplane probably would be affected more critically by a rapidly changing headwind component typical of a low-altitude, wind-shear penetration. I do not mean to imply that a low-altitude wind-shear cannot threaten the safety of the slower propeller-driven airplane. Wind shears have been recorded of such high magnitude that a low-altitude penetration would not be possible in any airplane.

Since 1970 the Safety Board has identified low-level wind shear as a cause or a contributing factor in 15 accidents involving transport category airplanes. Nine of these accidents were nonfatal, but the other 6 accounted for 440 lives. Five of the fatal accidents and at least seven of the nonfatal accidents occurred after the airplanes encountered the convective downburst or microburst winds associated with thunderstorms or heavy rain showers.

The accidents attributed to convective wind-shear have occurred during landing approach, attempted go-around, and takeoff phases of flight. One fatal accident occurred during a landing when the airplane encountered a wind-shear caused by a feature of the surrounding terrain—the wind-shear was cited as a contributing factor. The two remaining accidents, both nonfatal, occurred after the airplanes passed through frontal system boundaries during the landing approach.

The fact that these accidents were not fatal should not be interpreted to indicate that a frontal wind-shear is not a dangerous threat. To the contrary, one of the accidents involved a DC–10 airplane which struck the approach light piers and seawall embankment during an instrument landing system approach at the Boston Logan Airport in December of 1973. The airplane was substantially damaged when the landing gear sheared off, and there were serious injuries during crew and passenger evacuation. It could have been much worse.

It was this accident which first prompted the Safety Board to recommend that wind-shear be included in pilot training programs and that the development of wind-shear detection systems be expedited.

The crash of an Eastern Air Lines 727 inbound to JFK Airport on June 24, 1975, cost 113 lives. That accident occurred when the airplane encountered the outflowing winds and downdraft associated with a thunderstorm on final approach. The airplane experienced a rapid loss of airspeed and developed a high descent rate from which it did not recover.

Following the investigation of the accident, the Safety Board issued 14 more safety recommendations which addressed the development of both ground-based and airborne equipment for detecting wind-shear, the determination of operational limitations for various types of aircraft, the enhancement of airborne vertical guidance equipment, and the need for enhanced pilot training programs.

Acknowledging the serious hazard of wind-shear, the FAA and other Government and industry organizations began extensive research and development programs which were in general consonance with actions recommended by the Safety Board. The occurrence of three more air carrier accidents between 1975 and 1977 which were attributed to encounters with convective wind-shear placed more emphasis on the R&D efforts. Several positive actions resulted: pilot training programs were enhanced to increase flight crew awareness of the hazard; operational techniques were evaluated in simulation; various technologies for both ground-based and airborne wind-shear detection and monitoring equipment were evaluated.

Unfortunately, the tangible benefits of the R&D programs which have been underway for the past 8 years have not yet been realized. The only operational, wind-shear-detection system implemented thus far is the LLWAS, an anemometer array around the airport which will alert the tower controller to shifting ground-level winds. The limitations of the system were recognized, and it was touted as an interim measure until more sophisticated equipment was developed.

The limitations of the LLWAS as an operational decisionmaking aid to flight crews were accentuated by the tragic crash of a Pan American 727 during takeoff from New Orleans on July 9, 1982. Although the LLWAS indicated wind-shear in the vicinity of the airport prior to the takeoff—there was no LLWAS alarm at the time of the takeoff—there were no established means to relate the information to the hazard of a particular takeoff. Consequently, the flightcrew of the accident aircraft did not perceive the danger, and 153 persons died when the flight encountered a characteristic microburst at or immediately after the point of takeoff.

The Safety Board again recommended actions to be taken by the FAA, several of which addressed the need to improve the current technology systems so that they could be used effectively for flightcrew operational decisions. Other recommendations addressed the use of the wealth of information which was gained from the Joint Airport Weather Study Program at the Denver airport to its best advantage. That information should be used to improve the LLWAS system and to evaluate the potential of other technology, such as the microwave doppler radar, for detecting wind-shear and communicating information to controllers and pilots, and to provide better information for pilot training.

Mostly in response to congressional pressure, much of it coming from this committee, the FAA contracted with the National Academy of Sciences for a study of the wind-shear hazard and solutions for accident prevention. Dr. Townsend will be discussing the activities and findings of the National Academy committee in detail. These findings and recommendations were consistent with the Safety Board views.

One very important solution we should work toward is elimination of the problems by stressing avoidance—that is, by providing pilots with all of the information required to tell them not to attempt flight in the vicinity of a wind-shear threat. Second, since avoidance probably never will be achieved totally, we must provide pilots with all of the tools and knowledge to enhance their performance should they encounter a low-level wind-shear penetration.

Continued efforts must be made to accomplish the following:

We must improve wind-shear forecasting to define the conditions conducive to microburst development, and inform dispatchers and pilots when these conditions are present, as well as the wind-shear potential for frontal systems.

We must improve communications between the weather service, air traffic controllers, and pilots to assure that pilots are provided the most current forecasts and existing conditions for planning flights, landing approaches, and departures.

We must improve the real time detection of wind shear conditions by using the low-level wind shear alert system to its maximum potential and assuring optimum placement of anemometer array and optimum software alarm logic. Development and installation of microwave doppler radar equipment at airports located in areas of high microburst risk must be expedited.

We must assure that pilot training stresses avoidance of wind shear, particularly convective shears, and include discussions of the meteorological conditions conducive to the development of these shears.

We must assure, further, that pilot training programs include discussions of the aerodynamic performance problems associated with wind shear penetration, as well as simulations of wind shear encounters during all low altitude phases of flight, and stress the need for rapid recognition and response to use all of the airplane's performance capability. Pilots must be aware of the abnormally high control forces needed to use all of the airplane's performance in a wind shear encounter.

We must develop, certify, and install airborne equipment which can provide the pilot with warning of wind shear encounter so that avoidance measures can be taken. In addition, the logic of command guidance instruments must be optimized to enhance the pilot's response to the encounter.

In summary, the Safety Board will continue to advocate the immediate enhancement of LLWAS and improvement in the means of communicating the information available to pilots. We intend to monitor the FAA's activities at New Orleans, where an enhanced LLWAS is being evaluated, and at Denver, where both the LLWAS and microwave doppler are being used to provide operational information to flightcrews.

We support the continued program for the next generation weather radar with microwave doppler with its wind measuring capability. The NEXRAD implementation will improve en route weather detection and avoidance. However, we do not anticipate that it will be a significant factor in the terminate area wind shear problem. Therefore, we will continue to place emphasis on the terminal doppler radar tests presently being conducted at Memphis. We hope that this program will continue to receive priority attention by the FAA. Operational procedures need to be developed for using these technologies for wind shear avoidance.

Mr. Chairman, I might say that I am very much concerned that the implementation of a lot of the technology that has been developed is going to require a lot of public money, and it's going to be required at a time when we are in financial straits as a government, to say the least. I think it is going to take a lot of follow-through by the FAA, but not only by the FAA—by the Secretary of Transportation, by the Office of Management and Budget, by the Congress and by the White House, to see that over a period of a decade these programs receive the funding that they are going to have to require to make these technologies an effective reality.

I think this will be very easy if we continue to have wind shear related catastrophes. However, it's going to require, I think, a lot of attention and follow through from the aviation safety leadership to get the kinds of funds that are going to be required in the absence of disasters, and of course we would like to be able to provide this in order to avoid disasters, rather than have it be developed as a result of them.

In another appearance before your committee, Mr. Chairman, on the subject of wind shear detection technology I stated that it is extremely frustrating to the Safety Board that the only tangible action implemented was the FAA's installation of the low-level wind shear alert system, and we still do not know how to use that system effectively. That was almost 2 years ago, and the situation today is unchanged.

The day that the Denver accident occured, the United Air Lines Denver accident occurred, Mr. Laynor was giving a speech to a group on wind shear down at the Langley facility. At that time he posed the question: Even though the Safety Board has generally been satisfied with the response to our recommendations made following the New Orleans accident—he posed the question—are things any safer today than they they were then? I think perhaps early that day our answer might well have been no.

I think we have seen in the course of the investigation of the Denver incident that there has been an increased recognition on the part of pilots of the microburst phenomenon and additional training to deal with that. That may have avoided the kind of disaster at Denver that we had at New Orleans, so I am not prepared to say that we have made no progress, that no progress has been implemented. Certainly there has been progress toward some of our goals, but very little implementation of it, so the public safety, despite all the efforts has really not been improved in the way we would like.

Airborne wind shear detection technology needs more emphasis. Microwave doppler, laser, and infrared technologies offer promise, but they all require more research and development in testing.

Mr. Chairman, I commend you and your committee for your diligence in pursuing these technological improvements. Thank you for the opportunity to express the views of the Safety Board. That concludes my formal statement, and I would be pleased to answer any questions you may have.

[The prepared statement of Mr. Burnett follows:]

Safety Information

National Transportation Safety Board
Washington, D.C. 20594

TESTIMONY OF

HONORABLE JIM BURNETT

CHAIRMAN, NATIONAL TRANSPORTATION SAFETY BOARD

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

COMMITTEE ON SCIENCE AND TECHNOLOGY

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JULY 25, 1984

Mr. Chairman, I am pleased to have the opportunity to appear before you today to discuss the subject of wind shear detection technology. While testifying recently before another Congressional Committee I was asked what I thought is the greatest threat to aviation safety. My reply -- weather.

Since the beginning of aviation, weather has always been the one factor over which we have no control. We can only minimize its impact by learning more about it and avoiding the worst of it. Much work has been done with regard to wind shear, but recent incidents bring home the point that there is still a great deal left to be accomplished.

For example, less than six weeks ago a USAir DC-9 carrying 50 passengers and five crew members crashed while attempting a go-around following its approach to Detroit's Metro Airport. It appears that they flew into what is referred to as the wind shear phenomenon. The flightcrew began the approach at the time a heavy rainstorm was over the airport and the tower controller was announcing significant Low Level Wind Shear Alert System (LLWAS) warnings. Fortunately, only minor injuries resulted.

Testifying before the Safety Board last week at a deposition proceeding in Detroit, the USAir pilot provided a dramatic account of his efforts first to fly through the windshear and then his resignation in calling for the landing gear as his airplane literally was pushed from the sky.

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Less than two weeks prior to the Detroit wind shear encounter, a United Airlines B-727 struck a localizer antenna after taking off from the Denver Stapleton Airport in what turned out to be wind shear. In this case too there were low level wind shear alerts and other indications which might have prompted a decision to delay takeoff. Fortunately, the crew was able to avoid a disaster because of its training to use all of the airplane's performance capabilities in a wind shear encounter. There were no injuries in this instance either.

Wind shear has always been with us, although it is interesting to note that it has only been during this past decade that the aviation safety community has acknowledged wind shear per se as a serious aviation problem. While the conditions are rare which can produce a level of shear sufficient to override normal airplane performance, we at the Safety Board believe that wind shear is probably a greater threat to airplanes now than it was twenty years ago.

One reason for this is the growth in the number of flight operations. Additionally, although wind shear does occur in otherwise relatively good weather, the most severe flight hazard is generally produced by the convective winds which are often accompanied by thunderstorms or heavy rainshowers, the type of weather that generally used to keep airplanes on the ground. Advancements in both bround-based and airborne navigational, guidance and control systems undoubtedly have contributed to more frequent flight into this type of weather condition.

Another possible reason concerns the evolutionary changes in airplane design. Each new generation of airplanes has brought advances in performance -- defined by speed, range, payload, and specific fuel consumption. It does not necessarily follow, however, that the pilot of a modern high performance airplane can cope with a wind shear encounter any better or even as well as a pilot of a straight-wing, propeller driven airplane. In fact, an analysis of airplane performance indicates that a swept wing turbojet airplane probably would be affected more critically by a rapidly changing headwind component typical of a low altitude wind shear penetration. I do not mean to imply, however, that a low altitude wind shear cannot threaten the safety of the slower propeller driven airplane. Wind shears have been recorded of such high magnitude that a low altitude penetration would not be possible in any airplane.

Since 1970 the Safety Board has identified low level wind shear as a cause or contributing factor in 15 accidents involving transport category airplanes. Nine of these accidents were nonfatal, but the other six accounted for 440 lives. Five of the fatal accidents and at least seven of the non-fatal accidents occurred after the airplanes encountered the convective downburst or microburst winds associated with thunderstorms or heavy rain showers.

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was cited as a contributing factor. The two remaining accidents, both non-fatal, occurred after the airplanes passed through frontal system boundaries during the landing approach.

The fact that these accidents were not fatal should not be interpreted to indicate that a frontal wind shear is not a dangerous threat. To the contrary, one of the accidents involved a DC-10 airplane which struck the approach light piers and sea wall embankment during an Instrument Landing System (ILS) approach at the Boston Logan airport in December 1973. The airplane was substantially damaged when the landing gear sheared off, and there were serious injuries during crew and passenger evacuation. It could have been much worse.

It was this accident which first prompted the Safety Board to recommend that the FAA require that wind shear be included in pilot training programs and that the development of wind shear detection systems be expedited.

The crash of an Eastern Air Lines B-727 inbound to JFK airport on June 24, 1975 cost 113 lives. That accident occurred when the airplane encountered the outflowing winds and downdraft associated with a thunderstorm on final approach. The airplane experienced a rapid loss of airspeed and developed a high descent rate from which it did not recover. Following the investigation of the accident, the Safety Board issued 14 more safety recommendations which addressed the development of both ground-based and airborne equipment for detecting wind shear, the determination of operational limitations for various types of aircraft, the enhancement of airborne vertical guidance equipment, and reiterated the need for enhanced pilot training programs.

Acknowledging the serious hazard of wind shear, the FAA and other government and industry organizations began extensive research and development programs which were in general consonance with actions recommended by the Safety Board. The occurrence of three more air carrier accidents between 1975 and 1977 which were attributed to encounters with convective wind shear placed more emphasis on the R & D efforts. Several positive actions resulted: pilot training programs were enhanced to increase flightcrew awareness of the hazard; operational techniques were evaluated in simulation; various technologies for both ground based and airborne wind shear detection and monitoring equipment were evaluated.

Unfortunately, the tangible benefits of the R & D programs which have been underway for the past eight years have not yet been realized. The only operational wind shear detection system implemented thus far is the LLWAS, an anemometer array around the airport which will alert the tower controller to shifting ground level winds. The limitations of the system were recognized and it was touted as an interim measure until more sophisticated equipment was developed.

The limitations of LLWAS as an operational decision-making aid to flightcrews were accentuated by the tragic crash of a Pan American B-727 during takeoff from New Orleans on July 9, 1982. Although the LLWAS indicated wind shear in the vicinity of the airport, there were no established means to relate the information to the hazard of a particular takeoff.

Consequently, the flightcrew of the accident aircraft failed to perceive the danger and 153 persons died when the flight encountered a characteristic microburst at or immediately after the point of takeoff.

The Safety Board again recommended actions to be taken by the FAA, several of which addressed the need to improve the current technology systems so they could be used effectively for flightcrew operational decisions. Other recommendations addressed the use of the wealth of information which was gained from the Joint Airport Weather Study (JAWS) program at the Denver airport to its best advantage. That information should be used to improve the LLWAS system and its procedural use to evaluate the potential of other technology such as the microwave doppler radar for detecting wind shear and communicating information to controllers and pilots, and to provide better information for pilot training.

Mostly in response to Congressional pressure, the FAA contracted with the National Academy of Sciences for a study of the wind shear hazard and solutions for accident prevention. Dr. Townsend will be discussing the activities and findings of the National Academy committee in detail. These findings and recommendations were consistent with the Safety Board views.

One very important solution we should work toward is elimination of the problems by stressing avoidance -- that is by providing pilots with all of the information required to tell them not to attempt flight in the vicinity

of a wind shear threat. Secondly, since avoidance probably never will be achieved totally, we must provide pilots with all of the tools and knowledge to enhance their performance should they encounter a low level wind shear penetration.

Continued efforts must be made to accomplish the following:

-- We must improve wind shear forecasting to define the conditions conducive to microburst development and inform dispatchers and pilots when these conditions are present, as well as the wind shear potential for frontal systems.

-- We must improve communications between the weather service, air traffic controllers and pilots to assure that pilots are provided the most current forecasts and existing conditions for planning flights, landing approaches and departures.

-- We must improve the real time detection of windshear conditions by using the Low Level Wind Shear Alert System to its maximum potential and assuring optimum placement of the anemometer array and optimum software alarm logic. Development and installation of microwave doppler radar equipment at airports located in areas of high microburst risk must be expedited.

-- We must assure that pilot training stresses avoidance of wind shear, particularly convective shears, and include discussion of the meteorological conditions conducive to the development of these shears.

-- We must assure further that pilot training programs include discussions of the aerodynamic performance problems associated with wind shear penetrations, as well as simulations of wind shear encounters during all low altitude phases of flight and stress the need for rapid recognition and response to use all of the airplane's performance capability. Pilots must be aware of the abnormally high control forces needed to use all of the airplane's performance in a wind shear encounter.

-- We must develop, certify and install airborne equipment which can provide the pilot with warning of wind shear encounter so that avoidance measures can be taken. In addition, the logic of command guidance instruments must be optimized to enhance the pilot's response to the encounter.

In summary, the Safety Board will continue to advocate the immediate enhancement of LLWAS and improvement in the means of communicating the information available to pilots. We intend to monitor the FAA's activities at New Orleans where an enhanced LLWAS is being evaluated and at Denver where both LLWAS and microwave doppler are being used to provide operational information to flightcrews.

We support the continued program for the next generation weather radar with microwave doppler with its wind measuring capability. The NEXRAD implementation will improve enroute weather detection and avoidance; however, we do not anticipate that it will be a significnt factor in the terminal area wind shear problem. Therefore, we will continue to place emphasis on the terminal doppler radar tests presently being conducted at Memphis. We hope that this program will continue to receive priority attention by FAA. Operational procedures need to be developed for using these technologies for wind shear avoidance.

Mr. Chairman, in another appearance before your Committee on the subject of wind shear detection technology, I stated that it is "extremely frustrating to the Safety Board that the only tangible action implemented was the FAA's installation of the low level wind shear alert system ..." and we did not know how to use that system effectively.

That was almost two years ago, and the situation today is unchanged.

Airborne wind shear detection technology needs more emphasis. Microwave doppler, laser and infra red technologies offer promise, but they all require more research, development and testing.

Mr. Chairman, I commend you for your diligence in pursuing these technological improvements and thank you for the opportunity to express the views of the Safety Board. That concludes my formal statement, and I would be pleased to answer any questions you may have.

Mr. GLICKMAN. Thank you, Mr. Burnett.

We have been joined by Mr. Gore, and I am going to call upon him in a minute for a short statement but I am going to have to rush out of here pretty soon and I just want to ask you a couple of quick questions.

You have made some recommendations about pilot training and getting on with the technology. What do you recommend in the very short term, the next several months, as ways to improve against the risk of these kinds of accidents occurring?

Mr. BURNETT. Mr. Laynor?

Mr. GLICKMAN. I want to know what the FAA ought to be doing now, what airliners ought to be doing now, what pilots ought to be doing now, in the next 6 months.

Mr. LAYNOR. Well, I think that we are convinced that there are a lot of actions that are being taken. They were being taken before these last two accidents that we are investigating and they are still underway. Obviously training is one thing that you can address directly. It doesn't require the development of a lot of hardware and the expenditure of a lot of additional funds and such, and there are intensive efforts being taken to increase pilot awareness. Manufacturers—in fact, both the Boeing Co. and McDonnell Douglas—have come out with extensive literature to the pilots of their aircraft. Just within a month before these last two accidents, McDonnell Douglas published a whole issue which treated the subject of wind shear, both descriptions of the wind shear phenomena, how to recognize it, how to avoid it, and what to do if you get in it. Boeing has also addressed these areas.

The Air Transport Association has initiated a wind shear task force, and I think today as we talk that task force is convening for its second meeting, which was also scheduled in advance of these last two accidents. I'm sure that they will be discussed and we have learned a little bit, and some of the information from those accidents will make their way into that meeting, but the purpose of the meeting is to again address what effective training is needed to tell pilots how to recognize a situation, when to delay takeoff, when to delay their starting of approaches and, too, how to handle the airplane if you happen to become exposed to it.

Mr. GLICKMAN. What about the FAA? I guess what worries me is that one of the effects of deregulation has been to jam certain airports with just an ungodly amount of traffic, and the controllers—to the extent that we have any—you know, I mean, they have to worry about keeping airplanes from colliding with each other, vis-a-vis what happened yesterday at Kennedy Airport. I mean, do they have the capability to focus on weather?

Mr. BURNETT. Well, I think there are some tradeoffs there, and we don't want the air traffic control system to be focusing on weather and not focusing on separation of aircraft. I think that, of course, has been one of the FAA's concerns. We do believe that we can do a better job of providing weather information to the cockpit than we are presently doing, and I think that is, of course, one of the issues in our investigation of the Detroit accident.

I think certainly we need to maintain the appropriate restrictions on traffic that will allow the air traffic control system to handle effectively the traffic they have, and have the required time

to inform pilots of rapidly developing weather situations. That is a necessity not only for the success of our air traffic control system but for dealing with the wind shear problem.

Mr. GLICKMAN. Would you support the development of an airport wind shear or microburst alert system that could be used as a criterion for temporarily suspending operations at an airport?

Mr. BURNETT. Well, there's a lot of difficulties with that. I think yes, we would support the development of that, but we don't have it at hand. It's not a short term matter at all. Remember, the only thing we have right now, objective indicator, is the LLWAS system. It indicates the presence of wind shear but, remember, wind shear is relatively common. It is rare for it to be of such intensity and affect aircraft at the particular points at which they are at low level, low altitude, so that it becomes a critical factor.

But simply the use of the LLWAS alert—the fact that there is a wind shear in, say, one quadrant—would perhaps be killing ants with a backhoe. It could cripple our air traffic system and, in the process of doing that, develop other safety hazards, so we are not prepared to recommend that at this time. I think once we get recorders on the LLWAS systems—and the FAA is in the process of doing that—and we can study how often we have the wind shear alerts through that system, we can begin perhaps to develop some criteria that would be sufficiently conservative to enable pilots to avoid at least a major portion of the threat while at the same time not debilitating the air transportation system.

Mr. GLICKMAN. But, in addition to the LLWAS, however, there is no reason why there can't be better weather information available to controllers, particularly at the terminals.

Mr. BURNETT. Yes; I think that it certainly needs to be improved. The weather information that's available to the controllers needs to be improved. The weather information that's provided by controllers to pilots needs to be improved, but I think probably the best opportunity to avoid this type of situation in the short run is to better train the pilots to use the low-level wind shear alert system in conjunction with other information that is provided to them to avoid the situation. I think in both the Denver and Detroit investigations we see some indications that there was information provided that should have been sufficient for an alert. Certainly in the investigation of the United accident in Denver, there was a sufficient level of alertness to use increased thrust in anticipation that wind shear might be present, but it still has to be left right now as a matter for judgment in the cockpit, and the pilot needs to have the opportunity to consider the objective information that is given to him together with his own assessment of the weather situation.

Mr. GLICKMAN. Thank you.

Mr. Gore?

Mr. GORE. Thank you very much, Mr. Chairman. I'm sorry that I was a few minutes late when the gavel banged, but I had another obligation, and I want to apologize to the witnesses because I'm going to also have to go to a hearing on arms control where I'm making a statement, but then I'm going to come right back up here and finish out this hearing because it's one that I am extremely interested in. I have worked on it quite a while. Indeed, 2 years ago, Mr. Chairman, you and I held joint hearings on wind shear

and as a result of those hearings we have seen this renewed emphasis on the part of the FAA and the Safety Board, which had a prior interest on it, and I want to continue to monitor this progress.

When the witness from the FAA testifies, the fourth or fifth witness of this hearing, Mr. Blake, I intend to have a number of questions about the project underway in Memphis, TN. I am very pleased that Memphis, TN, is going to be on the cutting edge of this high technology effort to improve our ability to avoid wind shear accidents. They are one of the most terrifying and disturbing causes of airplane accidents because, until recently, there has been very little we could do to avoid their occurrence. We can design better machines to reduce pilot error, change our engineering to alleviate design errors, but with wind shear accidents such as the Pan Am crash in New Orleans or the recent USAir incident in Detroit, there has been a sense of helplessness. The pilots have been virtually helpless because we have been unable to even find wind shears until very recently, and what you can't find, you can't fight.

Experts say the best way to cope with wind shear is to treat it like an enemy and simply avoid it. Thus I'm very hopeful because we seem to be on the verge of taking some real strides toward having the ability to give our pilots reliable and up-to-the-minute information about the location of these wind shears and hence make our air traffic system a safer one.

For the present, the low level wind shear alert system is a step in the right direction, but the advances in doppler radar are much more exciting, in that this technology holds the promise of giving controllers quick, precise information about the location of wind shears and help guide our pilots in safer paths. I'm pleased that the FAA has plans to utilize this technology in our new generation of air traffic control systems, and I'm even prouder that the Memphis Airport will be the site to test these devices for terminal air traffic control.

It has been established that an aircraft flying at cruising speeds stands a pretty good chance of making it through the wind shears, but an aircraft taking off or landing is by far the most vulnerable because of slow speeds. The accidents in New York, Denver, New Orleans, and Detroit are morbid proof of that vulnerability and risk. Thus, if the project in Memphis can apply doppler radar and other technologies to substantially reduce that risk, it deserves our full support. I believe it will work, and it certainly has my full support.

As I said earlier, I look forward to questioning the FAA closely about the progress that we can expect to see in the Memphis project. With you, Mr. Burnett, let me just say again you know of my respect for the job you have done. Maybe you don't get tired of hearing it but really you have been a breath of fresh air over there, and you have really taken an aggressive and commonsense approach to the mandate of the NTSB. We all appreciate the work that you have done.

Am I correct in saying that the doppler system, when we get the bugs out, when we get it working smoothly, is going to be able to give us much more precise and accurate information about wind shear than the current low-level technology?

Mr. BURNETT. Oh, yes; that's what we're dreaming of. The doppler system and its real time information that can be provided in the cockpit is, of course, the goal and will, I think, be the solution, at least as far as—well, I know there will be testimony later here today about some other techniques, infrared and others, that may have possibilities and I don't want to throw any cold water on those. We need to be looking at all of them but we're very hopeful that we will have that kind of capability. I think, however, it is going to—it is a fairly long-term project in terms of governmental action and the kind of sustained appropriations and major appropriations that are going to be involved to implement it. Again I state, the concern that I have is that absent catastrophes in the interim, we may do what we did between 1977 and 1982. Even though we were alerted to this problem, we really didn't keep our eye on the ball in view of the fact that we were not experiencing the penalty of wind shear, so I think we are going to have to. It is incumbent upon all of us as public servants and as leaders responsible for allocating these resources, to maintain interest and be sure that the public is aware of the necessity of developing these systems.

Mr. GORE. Well, obviously much more needs to be done. We are going to explore that throughout this hearing today, but I must say that thanks to your efforts and, I believe, thanks to the work of these two subcommittees, or this subcommittee in particular and my subcommittee when we had the joint hearing 2 years ago that kicked off this emphasis on wind shear, I am very pleased that this project is being undertaken and that the cutting edge of it is going to be in Memphis, TN. We are proud of that fact and we are going to look forward to some very productive results in saving lives as a result of that project.

Mr. BURNETT. We are even proud of it across the river in Arkansas.

Mr. GORE. Thank you, Mr. Chairman.

Mr. CARNEY [acting chairman]. Mr. McCandless?

Mr. MCCANDLESS. Thank you, Mr. Chairman.

Mr. Burnett, on July 18 in the Washington Post a summary of the incident that happened at Detroit was written by the staff writer. I would like to use that as a point for discussion, and some of the areas in which the writer of this article addressed what appeared to be, from the testimony that he was writing on, deficiencies in the current system, building somewhat on what our chairman said earlier about what are we going to do now, not what does the grand scheme of things call for in the future that we work toward.

The one point here to begin with was the quotation that the pilot in question was unfamiliar with some new information about wind shear. One could draw a conclusion from that, (a) that the pilot was not required to know certain things by either the airline or the certifying agency, or (b) he didn't care, or the airline was deficient in its training program. The airline does go on to talk about some kind of clash of personalities between the pilot in question and the instructors, and low proficiency ratings and so forth.

That would be my first question. Do you have anything you want to comment on relative to that?

Mr. BURNETT. Well, I am not prepared at this stage of our investigation and analysis to answer whether it's (a), (b), or (c), or all of the above or none of the above. However, those are certainly some very serious questions that we are looking at in the course of our investigation.

There had been some check ride performance problems on the part of the pilot involved, so we have to look at it from his individual characteristics, but we also have to look at the training program that was provided to all of the pilots in that airline. We did have some pilots who decided not to make that approach that day with basically the same or similar information, perhaps, that the pilot in question had, so we have to look at what made the difference. It may be individual pilot judgment. It also may be the training programs that were provided to them, so those are areas that we will look at in the course of the investigation.

Mr. MCCANDLESS. Would you include in that, going on here, that the pilot in question lacked knowledge of equipment and procedures? Would you lump that into the same category as the unfamiliar with some new information?

Mr. BURNETT. Well, I don't want to appropriate the language of the article as mine. There certainly was some question about the pilot's understanding of the procedures that he was supposed to use in this situation, and I think that conclusions on that point need to be made by the whole board and not me here today, but that is certainly a serious question. About the equipment, I really don't know what the article is referring to in that situation.

Mr. MCCANDLESS. I am not trying to put the pilot or you——

Mr. BURNETT. That's all right.

Mr. MCCANDLESS [continuing]. But these things have been around for quite a while.

Mr. BURNETT. I think yes, they have. We have recognized windshear as a problem, certainly, generically for a long time but you have to realize that it is just in the past couple of years that the most serious wind shear manifestation, which is the microburst, has been recognized and we began to be able to train pilots on how to deal and the very serious nature of that particular phenomenon, so I think that it might be a little misleading to say that. We certainly are developing our knowledge of wind shear very rapidly right now, and over the last years and months.

Mr. MCCANDLESS. I guess I'm a nuts and bolts procedural type and that's why I'm dwelling on this, but we go back to—when was the first incident that was recognized as wind shear?—1975, somewhere along in there?

Mr. BURNETT. Oh, prior to that.

Mr. MCCANDLESS. Well, this was July 17 of this year. The importance of the knowledge, the importance of the training, the importance of the equipment and the procedures is just as great now as it would have been last year or the year before or the year after it was discovered, yet we're talking about all kinds of sophisticated devices and procedures and policies and equipment that would give us additional meteorological information.

I need to be convinced that the day-to-day policies and procedures required of these airlines in the training of their pilots since this was recognized some—what?—10, 12, whatever number of

years ago, are in fact there, and that the information is disseminated and that it's a part of the training process, and if the individual is not capable of assimilating it then the individual is not capable of flying.

Mr. BURNETT. I think, however, we must recognize, it's very important to recognize that some of the most crucial information that the pilot needs to have about what problems a wind shear poses to him and how he should deal with it has not been available until the last 2 years, and we are still in the process of developing that, so you can't really say that all of this has been available for 10 or 12 years. Certainly, we have been learning a whole lot about wind shear in the course of that, and some of it is a very recent acquisition.

Mr. Laynor?

Mr. LAYNOR. Well, the Joint Airport Weather Study Program which was conducted at Denver, and used microwave doppler and many other technologies to look at the microburst phenomenon, brought about a wealth of information regarding the actual physics of the phenomenon, the velocities of the winds and the way they behave, that are just being analyzed today. There are committees of people around taking a look at that data to see how it can best be implemented into development of better simulator models and better technologies to address the problem.

It is true that during the last 10 years there has been a disparity, probably, among the air carriers depending on the sophistication of their simulator equipment. Those with the newer, wide-bodied airplanes and the more modern simulators have probably gone a step beyond some of the carriers that are flying older airplanes in training pilots to deal with the phenomenon, but there is a lot of activity that is being taken today to improve that.

Mr. BURNETT. I realize the frustration in not having, perhaps, a simple answer to the question. For instance, how do we use the LLWAS system? The LLWAS system is of fairly recent vintage. It is not something that can be simply used by itself for determining whether or not a landing or a takeoff should be made or canceled. It needs to be used in conjunction with other observations of weather. I think we are certainly concerned about the kind of training that the pilot in question in Detroit had in making those judgments but, on the other hand, we found in the United accident in Denver—we also have some questions about the judgment on takeoff there—but certainly the information that has very recently been made available about how to deal with the microburst situation was implemented by the flight crew in that case, and they saved that aircraft from disaster. So, there has been some progress and I think it is, at this stage, perhaps somewhat uneven within the industry, and I mean from airline and from pilot to pilot within each airline, in terms of the kind of study, individual study, that they have given to it.

Mr. MCCANDLESS. I have had quite a bit of experience in the trucking business, and there are certain basic procedures when an 18-wheeler gets into a problem, that a good driver is able to avoid many accidents by using driving techniques. Now, maybe that's an oversimplification of what I'm talking about, but this thing has been around quite a while.

The other question I would like to talk about here is, again referring to this article and this particular incident, "The storm was almost an explosive development." quoting the meteorologist who testified. Are we saying here, to a degree, or could we say that this particular plane got more involved in weather than it did wind shear, because the article does refer to intense hail and other aspects of a weather front? I'm not trying to get you to try this particular case here in front of us.

Mr. BURNETT. Well, I think we do want to look at that. We do believe that wind shear was present there, but there was intense hail, and there is certainly a theory being discussed now that we have not really battened down very well, that rain, for instance, heavy rain can affect an aircraft's performance, and it raises questions: What about the effect of hail?

Mr. Laynor, would you want to comment?

Mr. LAYNOR. Well, certainly it's a possibility that there are some aerodynamic performance penalties put on an airplane by rain. They haven't really been quantified. I think the research people and academic people in the business think that they are probably minor compared to the wind effects of a microburst or downburst, but there have to be activities, research activities to look at that. There is something that is getting started, however, I think it's having problems getting underway too, at NASA-Langley to do some wind tunnel testing to really quantify a little bit better the rain effects on airplanes.

One other aspect I would like to address, though, on the LLWAS system and the information it provides, we have made recommendations that concern the way in which the low-level wind shear alert system information is conveyed from the tower controller to the pilot today, and the pilot has to do the mental calculations when he gets that information to take the direction and speed of the wind readings that are given him, to try to figure out whether that is going to be a problem to his aircraft. Now we do think that there are some improvements that could be made relatively easily with software changes to the system to convey that information in a more meaningful way to the pilot, and we hope that the FAA's New Orleans and Denver activities will produce some of these improvements.

Mr. MCCANDLESS. Maybe you ought to answer my next question, but again to continue on with the article, it said that the airport's low-level wind shear alert system was working but the controller never used the words "wind shear alert" as procedures require, in a series of transmissions concerning strong winds, wind shifts, at the airport. Are we talking here about potential human error on the ground creating human error in the air?

Mr. BURNETT. Well, we are certainly going to have to look at it. Those are certainly issues, and air traffic control system performance is an issue in this investigation.

Basically what took place, the controller broadcast the winds that were—enough information for the pilot to be able to know that he was being given wind shear information. We do not think that, except for maybe the exceptional individual, anyone receiving that information would have been able to make the sophisticated computations that would enable them to know exactly—to give

some idea of what the performance effect of this wind shear was going to be. The words "alert" or "warning" were not used but in fact that information is never broadcast unless it is, in effect, an alert is in progress, so we have questions on both sides: Why wasn't the pilot provided with this information, or why wasn't the term "alert" used or "warning" used? On the other hand, why didn't the pilot recognize that it was a warning from the information that he was receiving? So all of that has to be explored and some fairly sophisticated analysis is going to have to go into it. However, I think it is quite clear that basic procedures that the airline had in place were not followed in making the judgment to go ahead and make the approach and landing in this situation.

Mr. McCandless. Finally, if I may, Mr. Chairman, the last part of this—and these all seem to be points that I think are worthy of discussing, and I am using the Detroit incident solely as not trying to place anybody in a fishbowl—the tower radio frequency was so busy, according to the cockpit voice recorder, that the pilot searching in rain and hail for the runway said to his copilot, "Ask them if they've got the runway lights on. I can't get a word in edgewise."

We have an intense weather front. We have a high-use airport. We have high-use air controller dialogue because of all these factors. Now we can spend billions of dollars and put additional equipment on the ground, but are we going to correct a situation when all of these factors find themselves at one place at one time?

Mr. Burnett. Go ahead.

Mr. Laynor. Well, it's certainly a problem. When the worst weather comes about is when times get busiest, and that was evident in that case. In the long-range future we look to some of the data link activities that are in the mill for the future generation air traffic control systems to alleviate some of the problems, certainly, but we too recognize that they are probably in the 1990's and they are not right around the corner. But when that system comes about they will be able to transmit information to several aircraft at the same time in a means that does not require verbal communication, so there is less room for error and certainly there is a lot faster transmission means.

Mr. Burnett. I think in relation to the air traffic control situation and the communications, they did have a very heavy workload, the ATC system did, on that day because of the thunderstorm and the traffic they had. Not only the pilot in question but other pilots, some of whom made the decision not to complete the approach, were—reported to us that they were having difficulty in communication because they were so busy in the tower. Also it was reported to us during the testimony by the pilots that they had experienced an increase in this over the last few months, so it seems to me to be clearly related to the increase we have in air traffic, and this situation might be remedied by—and it's one of the things we are going to have to look at—by having approach control for each runway, which of course would demand more manpower of the ATC system which already has more than it can handle with the traffic demands we have, so all of these problems are interrelated. As you point out, almost any solution at one point would create some problems somewhere else.

Mr. MCCANDLESS. Finally, if I may, Mr. Chairman, taking a page out of general aviation's book, "Man, if it's raining or you've got a problem, don't try to take off or land." Is that an oversimplification?

Mr. BURNETT. Well, it certainly would avoid a lot of these problems. Of course, wind shear, we have to keep in mind, is not necessarily associated with rain or even a thunderstorm. You can have very severe wind shear and not have that, although it's one of the things that has to be considered. But the demand of people who want to rely on air transportation to get them where they're going this afternoon makes it probably impermissible for us to cancel scheduled aviation flights the same way we might general aviation flights, and we have a lot of trouble with general aviation pilots who are not willing to do that even though the situation makes it imperative that they do so.

Yes, we could adopt some very conservative policies that would cut our risk of encountering wind shear very drastically, but we would have a situation perhaps akin to an ongoing winter storm all summer long, and so you have to balance out some of those considerations.

Mr. MCCANDLESS. You were present, I believe, during the discussion between the FAA and Continental and ALPA and all of that that took place here prior to our recess, and the fact that in the final analysis, whether the plane flies or not is the decision of the captain.

Mr. BURNETT. Yes, and I think that's a wise policy.

Mr. MCCANDLESS. Thank you very much. I have enjoyed discussing this with you, and I appreciate your coming before us today.

Mr. BURNETT. Thank you, Congressman.

Mr. MCCANDLESS. Thank you, Mr. Chairman.

Mr. CARNEY. As a person who strongly believes that we have the safest airways in the world in the United States, and the FAA does the best job that they can with the resources available to them, I must admit after reading that article on the incident out in Detroit, my confidence is shaken somewhat when you add all the things up that occurred in that one particular incident. It seems incredible to me that the plane was allowed to land. Am I right in assuming that that's totally the pilot's decision?

Mr. BURNETT. Well, I think we have to be very careful when we're talking about allowing a pilot to land, because if we're going to take it upon the Government or some authority to say, "You may not land," or "You may not take off" in these situations, we are going to have to write some fairly conservative guidelines. In other words, air traffic controllers are not in nearly as good a position to make that—they don't have the time nor the training. They are not in as good a position to make that decision as pilots, so it can't be left up to anyone else's judgment, in my opinion. We would have to write guidelines to say, "Under these situations you will go." If those are made conservative enough to really give us some major safety benefits, they may also close us down, so we're going to have to look at that and we really don't have the information available right now to draw that line in a way that we can on the one hand make substantial improvements in safety or reduce the risk of encountering a wind shear, and on the other hand be

sure that we're not going to totally disrupt the air transportation system.

In this case we have a lot of concerns about how the pilot exercised his judgment, with the information he had at hand. We also have concerns about information that could have been provided to him that was not, so we have to look at pilot training and his ability to exercise that kind of judgment, not only from his individual characteristics as a prudent person but also from the training that all pilots are given. We also have to look at the information that is being given to pilots and the form that it's being given to them, because they have a heavy workload and if it's not in a form that they can use—and basically the information that they're getting through the LLWAS system right now, which is if they're given winds in center field and in four quadrants and given wind speed and direction in all four of those quadrants, and it's given to them in the few seconds that an air traffic controller has to give it to them—it's not something that the human mind can handle. So most of the pilots that decided not to complete their approach were more concerned—or at least the way they determined this in their mind was—they were influenced by the potential for a high crosswind above the limitations of their aircraft upon landing. It wasn't the loss of lift necessarily that's involved in wind shear, although they were all cognizant of the potential for a wind shear, a microburst type of problem, in that situation.

Mr. CARNEY. I don't want to belabor this particular incident. I don't think it would be productive and, secondly, there is an ongoing investigation and certainly you are not in a position to say everything that might be available to you at this point, and I recognize that. But I would have to think that what could be a contributing factor to this particular accident and maybe others as well, is that there is a great demand on airports for takeoffs and landings, greater than the human ability is to cope with it. The article says there were 19 transmissions in 60 seconds from the air traffic controllers—19 in 60 seconds. That's 3 seconds a transmission. It had to be very confusing, because you add the storm and everything else and I'll tell you my confidence in flying has been diminished. But there has to be a point, a circuit-breaker point where the traffic load is so much that they just hit the breaker and say no one can come in: "Everybody go out and get in the chain again and come back down again when we have this under better control."

Mr. BURNETT. It's too late then, perhaps. What we advocate and what is a necessity for the safety of our air transportation system right now is sufficient flow control procedures that we do not have that kind of a situation developing.

Now of course you can have unexpected developments like a thunderstorm that can influence it, and obviously it did in this case, but we need to keep the intensity of the traffic at a level that the air traffic control system can handle it, and we will not have safe air transportation unless we do. I think it's at a very crucial point—and I'm glad you raised it—right now, because I believe that the new Administrator of the FAA has reimposed some of the traffic controls that the Safety Board has believed all along were necessary. We're getting some static about that now because obviously there are going to be delays, and the traveling public is going

to be unhappy about that, but I think it's a necessity that we maintain those controls if we expect to have a safe air transportation system.

Mr. CARNEY. Delays are one thing but there's something else: If you're running a subway system and the cars are scheduled 5 minutes apart and they come in every 5 minutes, that's not delaying the service, but if you don't have enough cars on each subway to take the people, they might not get from point A to point B in a timeframe convenient to them. Correct? That's not necessarily a delay. That's just saying the system can't handle the demand.

My point is this: Perhaps the system can't handle the demand and we're trying to cram 5 pounds of garbage in a 3-pound bag, and that, my friend, would be to me immoral, quite frankly. If we're going to tax the system to meet the commercial demand of people wanting to arrive at 5 o'clock at night and leave at 9 o'clock in the morning, then we're putting a lot of people's lives in jeopardy to do that. I'm sure we could come up with some operating procedures that would say you can have so many takeoffs and so many landings in an airport at any given time, and that's it. Once that reaches that point, no more. You can't saturate the airport. That's the point I'm trying to make. Rather than look at the individual case, it seems to me—I'm not looking at wind shear here. We have switched some emphasis, Jim.

Mr. BURNETT. I understand.

Mr. CARNEY. But what I am looking at is that obviously, by reading that article, if it is all true, and no one has said contrary to the article, that it isn't true, but obviously with all that activity at the airport there had to be an awful lot of planes in that area, maybe too many. That's the only point I'm trying to bring out, and it might be worthy—and I'm sure you are looking at that.

Mr. BURNETT. We are not only looking at it but——

Mr. CARNEY. I would like for you——

Mr. BURNETT [continuing]. But I have been making that same point for many months now, and——

Mr. CARNEY. Would you provide for the committee the amounts of takeoffs and landings scheduled at that airport an hour and a half before to an hour and a half after that incident?

Mr. BURNETT. We can provide it. I think the FAA probably could more readily do that. I don't know that it's in the course of our investigation.

Mr. CARNEY. We will ask the FAA to do that, then. Fine.

Mr. BURNETT. I think it's——

Mr. CARNEY. I understand your situation with an ongoing investigation, and that's why I would like to move off of that.

I would like to ask you, though, one more question. We have a rollcall vote and I know that your schedule is very busy. I appreciate your staying with us as long as you have.

The present situation that we have with the low-level wind shear alert systems seems to be one of the systems going off more frequently than necessary in the minds of the pilots and in the minds of the air traffic controllers. Would you like to comment on the system that we have now and whether that could be improved, whether we can set standards that——

Mr. BURNETT. Well, certainly the system we have now can and should be improved. Exactly how we're going to do it is another question. I don't think it's quite correct to say that it's going off more than it should. Basically, what we are receiving is information that indicates wind shear. The question is that there is some wind shear that doesn't necessarily present a danger to the aircraft, and that has to be analyzed and the information that the pilots are receiving does not help them analyze that very effectively. I think even someone who was a mathematical wizard would not be able to digest the information they are receiving and use it, and we don't have a procedure—and I'm not sure we even have the information available to develop a procedure—that would analyze it for them and give them sort of a final result: land or do not land. We just are not at that stage yet.

Mr. Laynor.

Mr. LAYNOR. Well, as I mentioned, we do think that it could be provided in a more clear form, if the wind shift is along the airplane's direction of flight, and whether it be an approaching or departing airplane, of just how it is going to affect his longitudinal component. It might be very meaningful to the pilot, but I think that we have to continue the research programs that are underway down at New Orleans with the enhanced LLWAS with additional anemometers in the array, and also at Denver where they are looking at the correlation between the information received by the microwave dopplers and the LLWAS system in order to get a better handle on how the information can best be conveyed to the pilot.

Mr. CARNEY. It has been indicated that the low-level system is set off by a 15-knot vector difference. Is that maybe too conservative? You see, what I am trying to get at is, from my understanding it seems to me that the system might be falling into a situation of crying wolf.

Mr. LAYNOR. Well, it may not be that that's too conservative. In fact, it depends on the placement of the disturbance. If you have, for instance, down at New Orleans on July 9, 1982, if you have a microburst that's out beyond the perimeter of the airport, it very well may be that 15 knots would barely alarm the existing LLWAS system because of the location of the anemometers. It's a matter of integrating an enhanced anemometer array and taking a look at the software system to see if there are other indicators of wind shear or rapid changes in direction on one sensor, for example. That might be just as meaningful as a 15-knot difference, if that one sensor is at the departure end of your runway, so that's the kind of thing that they are looking at constantly.

Mr. CARNEY. They would be making a model of it and trying to figure out the best——

Mr. LAYNOR. Yes, and, again, the recording capability of LLWAS when it comes to pass will certainly help us in retrospectively looking at the disturbances to see how they were displayed on the LLWAS.

Mr. CARNEY. Well, I think it is a matter now of time. We are implementing new techniques, new systems, and it's going to take time to have an understanding of them and just what's the best way to utilize them.

We have a rollcall vote on the floor of the House. Since there are only two Members here, I think it would behoove us to take a 10-minute break and we'll run to the floor of the House and come back.

Thank you, Mr. Burnett, for your testimony. As usual, it is very, very informative and straightforward, and we certainly appreciate that on this committee.

Mr. BURNETT. Thank you, and we thank the committee.

[A short recess was taken.]

Mr. CARNEY. The hearing will come to order.

Our next witness will be Capt. William W. Melvin, who is chairman of the Airworthiness and Performance Committee of the Air Line Pilots Association. Captain Melvin, we welcome you. I see you have a couple of familiar faces with you, Captain Melvin.

STATEMENT OF CAPT. WILLIAM W. MELVIN, CHAIRMAN, AIRWORTHINESS AND PERFORMANCE COMMITTEE, AIR LINE PILOTS ASSOCIATION, ACCOMPANIED BY JOHN O'BRIEN, DIRECTOR, ENGINEERING AND AIR SAFETY DEPARTMENT; AND JOE SCHWIND, DEPUTY DIRECTOR, ENGINEERING SECTION, ENGINEERING AND AIR SAFETY DEPARTMENT

Mr. MELVIN. Mr. Chairman and members of the subcommittee, I am Bill Melvin, chairman of the Airworthiness and Performance Committee of the Air Line Pilots Association. ALPA represents the professional interests of over 34,000 pilots who fly for 45 airlines. With me today is John O'Brien, on my right, director of ALPA's Engineering and Air Safety Department, and Joe Schwind, on my left, deputy director of our engineering section in the engineering and air safety department. We appreciate the opportunity to appear before you today to present the views of ALPA in regard to the current state of the art of wind shear detection technology and the use of this technology to make further improvements in the safety of our national airspace system.

Since 1969 ALPA representatives have been active in bringing the effect of wind shear upon aircraft to the attention of the aviation community. Prior to the tragic wind shear accident at Kennedy Airport in June 1975, ALPA had developed an explanation of the performance problems associated with the base area of downdrafts which was used in the defense of pilots accused of careless and reckless operation when they hit trees and power lines while making approaches beneath rain showers.

Since that accident, ALPA representatives have appeared before many congressional committees which were examining the relationship of weather and aviation safety. In our testimony we have stated repeatedly that additional improvements are needed in the forecasting and dissemination of aviation weather information. We have also identified two particular concerns with respect to weather conditions in the terminal area. They are, one, the systems installed at airports today to detect severe weather phenomena are grossly inadequate; and, two, the means intended to pass this information to the flight crew in a rapid manner are ineffective.

Mr. Chairman, we have particular concern over the inability to get accurate information on severe weather conditions in close

proximity to the airport. What is lacking is precise information on wind shear associated with downbursts, gust fronts, or low-level jet streams and heavy precipitation. Of particular concern is the availability of accurate information on the location of microbursts.

Because these phenomena are so localized and dynamic in nature, we need sensors which can acquire accurate data and then provide this information on a timely basis to flight crews. There are no systems installed at airports today which can provide this service, but we are encouraged by current research of a doppler radar technique which might prove to be an adequate sensor. This doppler technique is currently being used in a 45-day test program at Denver's Stapleton Airport.

In addition to detecting these phenomena, we believe that a concerted effort should be undertaken to develop forecasting techniques for microbursts. The Denver test program mentioned earlier may prove to be a catalyst for verification of forecasting techniques. Data from this program plus other information available today should enable short-term forecasting of the potential for microburst activity in the area immediately surrounding an airport.

If a short-term forecast for microburst activity was in effect coincident with a wind shear warning for a low-level wind shear alert system, the pilot would be in a much better position to judge the severity of the activity which confronts him. This additional forecast capability is necessary because wind-shear warnings from LLWAS have become commonplace. Therefore, if pilots were to halt operations every time an LLWAS alert occurred, our ATC system would be in total disarray during the summer months. We do not want to imply here that we should not stop operations for valid alerts. The problem has been the "cry wolf" syndrome.

Mr. Chairman, as you are well aware, the National Academy of Science has studied the wind shear problem and issued a report based on this study, and the FAA has responded to this report. Concerning the FAA's response to the Academy's wind shear report, we have one question: Has the FAA designated a program coordinator?

The National Academy of Science recommended revision of advisory circular AC-00-50A and forwarded, under separate letter, suggestions, primarily under separate letter because of constraints put on the committee by Congress. Due to the time interval to complete the report, there was insufficient time to complete the recommendations. Although the recommendations were initially proposed by me, they were jointly revised by myself and Capt. Bob Crump, vice president of Flight Standards and Training for United Airlines. He has since retired. They were circulated to all members of the National Academy of Science Committee and changed to reflect their input.

Although the advisory circular is fairly good in some areas, it is woefully out of date in description of microbursts. In fact, it does not even use the term. One of our greatest concerns is the recommendation to add 25 knots to the reference airspeed for takeoff without qualification as to the type of expected wind shear. A suggestion of this sort gravely understates the risk involved if a microburst encounter is expected.

We are disappointed that the FAA has, in several areas, deferred their responsibility to an Air Transport Association committee which represents only one view in the aviation community.

It is stated in the conclusion of the National Academy of Science report that "by improving the spatial and time resolutions of the surface wind measurements, LLWAS should be better capable of detecting the more dangerous wind shear conditions in the vicinity of airports." Specifically, we recommend computer analysis to detect a divergent wind pattern that is indicative of microbursts. In addition, the LLWAS needs short-term comparison of winds at individual sensors and an additional and higher alert level than at present which would be indicative of microbursts.

We continue to be concerned about recommendation for pilots to fly at very high angles of attack, near a stall, where ground impact is not imminent. This is generally referred to as the "stick shaker" technique. Unfortunately, the issue is thought by many to be highly polarized: Either fly on the "stick shaker" or don't. This is not the issue. The question of the "stick shaker" is when to use all remaining energy relative to the air mass. We think some reserve should be held to prevent or soften ground impact.

We are generally pleased with the FAA's caveats about flying on the "stick shaker" which appear in the advisory circular and the FAA training film. However, they do not mention concern over the possibility of premature stall of an airfoil when in heavy rain. Although the jury is still out on this subject, the possibility of stalling a transport aircraft near the ground is frightening. Some of these aircraft are known to have a tendency to become inverted when they are stalled.

Recent information from Dr. John C. Houbolt, of NASA Langley Research Center, concerning the likelihood of unequal spanwise wing loading in turbulence further heightens our concern over the risk of flying very near the stall speed unless ground impact is imminent.

The National Academy of Science recommended that angle of attack instrumentation should be added to the cockpit instrumentation of transport aircraft for use in maneuvering through wind shear. This has been a constant recommendation from a number of sources and would be a relatively inexpensive modification since transport aircraft use an angle of attack sensor to activate the "stick shaker."

We do not agree with the FAA's reservation against making angle of attack instruments mandatory. Airplanes are designed using angle of attack, they perform based on angle of attack, and test pilots use angle of attack to prove the designs. Such instruments have become standard in military aircraft and are generally provided on corporate jet aircraft.

However, we caution against using an angle of attack indicator as strictly an auxiliary instrument located in some obscure position on the instrument panel. It should be the primary reference indicator for performance flying and should occupy a prominent position on the instrument panel adjacent to or as an integral part of the attitude deviation indicator, possibly where the present airspeed indicator is located. There are some indications that some instru-

ments contain angle of attack and airspeed within the same instrument.

In summary, Mr. Chairman, we are pleased with the FAA's recent announcement of an experimental program of microburst forecast and microburst advisory at Denver. We believe that microburst forecast could be implemented at all airports soon, and microburst alerts could be issued upon detection of a microburst. If developed properly, short-term microburst forecasting could eliminate many of the decisionmaking uncertainties facing both pilots and controllers during wind-shear conditions.

Thank you.

[The prepared statement of Mr. Melvin follows:]

STATEMENT OF

CAPTAIN W. W. MELVIN

CHAIRMAN, AIRWORTHINESS AND PERFORMANCE COMMITTEE

AIR LINE PILOTS ASSOCIATION

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

COMMITTEE ON SCIENCE AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

JULY 25, 1984

WINDSHEAR DETECTION TECHNOLOGY

Mr. Chairman and members of the Subcommittee, I am Captain Bill Melvin, Chairman of the Airworthiness and Performance Committee of the Air Line Pilots Association. ALPA represents the professional interests of over 34,000 pilots who fly for 45 airlines. With me today is John O'Brien, Director of ALPA's Engineering and Air Safety Department and Joe Schwind, Deputy Director of our Engineering Section of the Engineering and Air Safety Department. We appreciate the opportunity to appear before you today to present the views of ALPA in regard to the current state-of-the-art of windshear detection technology and the use of this technology to make further improvements in the safety of our national airspace system.

Since 1969, ALPA representatives have been active in bringing the effect of windshear upon aircraft to the attention of the aviation community. Prior to the tragic windshear accident at Kennedy Airport in June of 1975, ALPA had developed an explanation of the performance problems associated with the base

area of downdrafts which was used in the defense of pilots accused of careless and reckless operation when they hit trees and power lines while making approach beneath rain showers. Since that accident, ALPA representatives have appeared before many Congressional committees which were examining the relationship of weather and aviation safety. In our testimony we have stated repeatedly that additional improvements are needed in the forecasting and dissemination of aviation weather information. We have also identified two particular concerns, with respect to weather conditions in the terminal area. They are:

the systems installed at airports today to detect severe weather phenomena are grossly inadequate; and

the means intended to pass this information to the flight crew in a rapid manner are ineffective.

Mr. Chairman, we have particular concern over the inability to get accurate information on severe weather conditions in close proximity to the airport. What is lacking is precise information on windshear associated with downbursts, gust fronts, or low level jet streams and heavy participation. Of particular concern is the availability of accurate information on the location of microbursts. Because these phenomena are so localized and dynamic in nature, we need sensors which can acquire accurate data and then provide this information on a timely basis to flight crews. There are no systems installed at airports today which can provide this service, but we are encouraged by current research of a doppler radar technique which might prove to be an adequate sensor. This doppler technique is currently being used in a forty-five day test program at Denver's Stapleton Airport.

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our greatest concerns is the recommendation to add 25 knots of the reference airspeed for takeoff without qualification as to type of expected windshear. A suggestion of this sort greatly understates the risks involved if a microburst encounter is expected.

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However, we caution against adding an Angle of Attack indicator as strictly an auxiliary instrument located in some obscure position on the instrument panel. It should be the primary reference indicator for performance flying and should occupy a prominent position on the instrument panel adjacent to or an integral part of the Attitude Deviation Indicator (ADI), possibly where the present airspeed indicator is located.

In summary, Mr. Chairman, we are pleased with the FAA's recent announcement of experimental program of microburst forecast and microburst advisory at Denver. We believe that microburst forecasts could be implemented at all airports soon and microburst alerts could be issued upon detection of a microburst. If developed properly, short-term microburst forecasting could eliminate many of the decision-making uncertanties facing both pilots and controllers during windshear conditions.

Mr. CARNEY. Thank you very much, Captain.

Mr. Gore?

Mr. GORE. Thank you very much, Captain.

What percentage of fatal air crashes are associated with weather? Do you know?

Mr. MELVIN. Well, weather in one way or the other, whether it's rain on a wet runway or in all of the weather phenomena that we have, I would say that weather would be a high percentage, probably 75 to 80 percent.

Mr. GORE. Seventy-five to eighty percent? We have figures only slightly lower than that.

Now wind shear accounts for what percentage of the crashes? We don't really know, do we?

Mr. MELVIN. Wind shear has accounted for a lot of them and a lot of risk involved, because there have been a lot of hard landings that were previously unidentified that were caused by wind shear. We really don't know that. We know the fatal ones that were caused by microbursts. We are fairly sure of those.

Mr. GORE. Yes. So, you believe that it should be an extremely high priority to develop and prove out systems that can more easily and more quickly identify these hazardous conditions such as wind shear and microburst and get the information quickly to the pilot in the cockpit. Is that a fair summation of your statement?

Mr. MELVIN. Yes, sir.

Mr. GORE. Well, that has been our principal interest in looking closely at this issue. Have you ever flown into Memphis, TN?

Mr. MELVIN. Yes, sir.

Mr. GORE. They have different kinds of thunderstorms. We have different kinds of thunderstorms in Tennessee, and particularly in Memphis. Are pilots generally aware of that fact?

Mr. MELVIN. Well, pilots are generally aware of the differences in thunderstorms. I think you may be referring to the fact that microbursts are classified as "wet" and "dry" and the type that come out of the thunderstorms that are very wet are typical of Memphis, and they are not the same kind that occur in Denver.

Mr. GORE. Yes. Now of the two kinds, which are most common?

Mr. MELVIN. Well, it depends on where you are located. If you were in Atlanta, or New Orleans, or Memphis, certainly the microburst occurring from the wet-thunderstorm type is very dominant. I don't really think you would have the kind that occurs in Denver. What occurs in Denver, the very high, dry climate prevents the rain shaft from reaching the ground and we have the thing that we call "virga."

The one thing that is characteristic of all microbursts is that they do come from cumulus cell activity.

Mr. GORE. So for most of the United States the wet microbursts would be the most common.

Mr. MELVIN. Yes; I think so.

Mr. GORE. Those are all the questions I have at this time.

Mr. CARNEY. Mr. Glickman?

Mr. GLICKMAN. Thank you, Mr. Carney.

I got in at the tail of the conversation. I apologize for missing your testimony.

I would assume that the dry microbursts are a heck of a lot harder to forecast because they are not accompanied by precipitation.

Mr. MELVIN. I'm not sure that that is correct. Dr. Caracena from NOAA has a technique for forecasting dry microbursts. I don't know whether that goes to the wet ones or not. The dry microburst is more difficult for the pilot, though, because most frequently you will have a layer of clouds and you will not see the cumulus build-up that is above that and it won't paint on radar, so a pilot will be taking off in what would be a generally benign condition and encounter a microburst, whereas in the wet case you almost always will have a painting on radar with a cell.

Mr. GLICKMAN. You are an active pilot?

Mr. MELVIN. Yes, sir.

Mr. GLICKMAN. Have you ever encountered low-level wind shear?

Mr. MELVIN. Oh, I have encountered low-level wind shear a number of times. I have never encountered a microburst, though.

Mr. GLICKMAN. OK, so you have never had a situation where on takeoff or landing you have had a very serious push-down of the airplane or however you would characterize it?

Mr. MELVIN. Yes, sir; I have. I have rotated at takeoff in a twin-engine airplane that had very good performance, and I have had to exceed the normal thrust level in order to clear the end of the runway and then finally came out of it. Now that would be a small—well, you might call it a microburst. We didn't call it that then, but the kind of microbursts that we're really talking about, though, no one is going to fly through that on takeoff or landing.

Mr. GLICKMAN. That they know about.

Mr. MELVIN. Yes, that they know about.

Mr. GLICKMAN. Let me ask you something: One of the things that has disturbed me for a long time is the lack of competent, on-time weather information to pilots on landing, the number of times that I will get on an airplane and the pilot will tell me what the weather is at the destination and we'll get there and the weather is nothing like that at the destination, nothing like it at all. It's amazing, in this period. I talk to the FAA and they say, "Well, that shouldn't happen. I mean, we have weather information coming through all the time." Then the pilot is confronted with being at a terminal area and having fuel reserves that are at certain levels, and the terminal is bringing airplanes in and in some cases there is not a heck of a lot of choice available for the pilot. Am I characterizing a common problem that pilots face?

Mr. MELVIN. A common problem that pilots face is a lack of adequate weather information, and that would be fairly common. We do have up-to-date sequence reports when we leave our destination, I mean, our departure airport, and then we are planning generally on what will occur at the destination. But especially in the summertime when you have thunderstorm activity, things change dramatically within the period of an hour.

Mr. GLICKMAN. Now, have you had a chance to look through either the transcript or the reports of what happened to this USAir pilot in Detroit?

Mr. MELVIN. No, I haven't. I have just heard a few rumors and I did not read the newspaper article that you are——

Mr. GLICKMAN. Well, according to at least the Washington Post article, his comments to the Safety Board were that the terminal controller was so busy, so jammed up with airplanes that apparently had been spaced further apart because of the weather, that in many cases he could not understand the information that was coming from them, nor was there any time for him to even communicate back to the controller, because it was like a taxi dispatcher, you know. It was just too fast. There was no time for thinking. Have you experienced that during bad weather?

Mr. MELVIN. Yes, I have. As a matter of fact, the controller has a primary job and that is to control the traffic and keep the airplanes away from each other. In this very dynamic situation where you have aircraft converging on the airport, it is frequently difficult for someone to step back and say, "Well, this is the big picture and we've got to curtail traffic now because of such-and-such." They are just—they have to keep up with the flow. You can't stop.

I have had a case coming into Washington National where the controller asked me if—they said, "The pilot on the flight in front of you reported severe turbulence," and I was about 6 miles out. I said, "Well, I want to vector around." He pulled me out and he changed the whole traffic pattern because of that, but generally that messes up the flow, when that happens, and they don't like to have that happen, really. They've got to go to "Plan B," I guess.

Mr. GLICKMAN. Thank you.

Mr. CARNEY. Would the gentleman yield at that point?

Mr. GLICKMAN. Yes, I would be glad to yield.

Mr. CARNEY. Captain Melvin, I think you would agree if you came down and were to crash your aircraft, that would also mess up the flow for a hell of a lot longer than just taking you out and sending you around once or twice.

Mr. MELVIN. Yes, that's true, and that's one of the things that—well, one of the problems has been a proper appreciation of the magnitude of the microburst, how severe it is. It has been consistently understated over many years.

Mr. GLICKMAN. Thank you. I have no further questions. I appreciate your coming here, very much.

Mr. CARNEY. Captain, in your testimony you said that you were particularly concerned about the recommendations to add 25 knots of reference airspeed for takeoff without qualification as to the type of expected wind shear. Could you explain that in better——

Mr. MELVIN. I think that recommendation comes from a misunderstanding of what can be expected in wind shear. In other words, if a pilot would anticipate a wind-shear condition as occurs in some places in Alaska and other parts of the world, where at a certain point, a certain geographic point or a certain altitude, he would expect a transition say to a tailwind condition, or at some geographic place he might expect wind shear out here, that might be an advisable thing to do. However, to recommend adding 25 knots to takeoff when you anticipate that the event that you may encounter could be a microburst, that seriously understates the magnitude of microbursts. The pilot in that case should stay on the ground. What it has done is understate—I mean, to pilots who read this material and who get training from their airlines that, well, if

you expect wind shear on takeoff add 25 knots to your takeoff speed—that implies that if you do that, that will take care of it.

Mr. CARNEY. What you are saying, then, is that by doing that you will give someone false confidence and, second, you are not getting the data necessary to make a good evaluation, that data being specifically what type of wind shear are you encountering and could that weather pattern create a microburst that no one should take off into.

Mr. MELVIN. Right. If it is anticipated that the particular takeoff could encounter a microburst, you shouldn't make the takeoff.

Mr. CARNEY. Let me ask you this, and I know you are not a meteorologist, but would you estimate how long microburst situations would be at an area that would affect the takeoff or landing of a plane? How much of a delay would you encounter if you were to wait for the weather to change to where you would reduce the risk of microbursts?

Mr. MELVIN. Well, a single microburst will only last a few minutes. Possibly the maximum intensity would be 2 minutes, but they don't occur in single events. In cases at Denver they have had microburst encounters that are close to runways, they have changed the runway, the pilots have come around to land on another runway and they have gotten hit by a microburst there, and they have changed it about three or four times.

In other cases, as occurred in New York when Eastern 66 crashed, there were multiple microburst encounters. We find in examination of ground destruction patterns that there will be multiple patterns where the microbursts hit; that the damage paths will be about the size of a football field where they tear down trees, which takes possibly, probably 80 to 100 knots of wind to knock the trees down. Those conditions can occur and can last 15 or 30 minutes, sometimes 45 minutes or an hour if there are large thunderstorms that are contributing to that.

Mr. CARNEY. Your recommendation which you specifically make for computer analysis to detect a divergent wind pattern that is indicative of microbursts, is it your belief that we have the ability to do that right now or is that something that we have to invent or improve on existing technologies to where it is——

Mr. MELVIN. Well, it's some—I beg your pardon. I get ahead of the question. Yes, we have the capability now. We have the measuring devices there, and even though they are not as dense as we would like to have them, I feel certain that if someone put the emphasis on that immediately it could be a very short time, that you would compare the readings from the various anemometers and build you another model in the computer that would identify a divergent flow. It would be another level of alarm than what we're hearing now as wind-shear alert. It is so low a level that it's going off so often that pilots are beginning to ignore it, but if they heard a higher level of alarm which was a microburst alarm or a microburst alert, where you had identified a diversion outflow, that would be much more significant.

Mr. CARNEY. What I think you're saying, and I'm not trying to put words in your mouth but I'm just trying to make sure that I'm understanding this, we have the measuring devices, that type of thing, but in order to get a good assessment of the weather condi-

tions at the airport that can be transmitted to the pilot quickly, you have to take all the input from these devices to completely understand the weather at the airport, put that into a computer so it can spill out the information. So it is a matter of taking available techniques of measuring wind occurrences and having them in certain areas, and having that input go into a single computer that could feed the information out instantaneously. Is that you're trying——

Mr. MELVIN. That's true. It would take something like a small personal computer, which they don't have this now. Another thing which we do not have is that there is no time history of an individual anemometer.

For instance, you may not have alerted because a front came by, but you don't know that the wind cell on the north field anemometer has changed in the last few minutes from a south wind to a north wind. This type of processing of the information has not been done.

Mr. CARNEY. I see, but you are convinced it can be done. It's a matter of spending the money and installing this type of equipment?

Mr. MELVIN. Yes, sir.

Mr. CARNEY. As I go through your testimony, which I thought was very, very good, by the way, you were also concerned about recommendations for pilots to fly at very high angles of attack coming into these situations, in fact, near stall angles, I guess. You refer to this as the "stick shaker" technique. Could you explain why they feel you should come in at the high angle of attack, for those of us who are not pilots, and could you also give us a brief description of the "stick shaker" technique?

Mr. MELVIN. Well, the "stick shaker" is installed on a transport category aircraft by regulation. It alerts at 7 percent above the certified stall. Now the certified stall is not what we call a 1 G mil spec stall, and when you talk performance, real performance, you have to talk 1 G mil spec. Because of that difference, and it is spelled out in the National Academy of Science report, the "stick shaker" only alerts at about 2 percent above a real 1 G stall, and you're very, very close to a full stall.

No one questions the use of flying using all available energy, pulling to the "stick shaker," if you've just taken off and you're about to hit the ground. I mean, certainly that is what you should do. The question, though, and the argument has been over the timing. There have been people who have come up with very simplistic solutions and said, "Well, any time you hit a wind shear you should pull the airplane up until you get the "stick shaker." They would imply that you do this at 200 feet above the ground, 300 feet above the ground, 500 feet above the ground. If this continues and some day a pilot encounters this, he is liable to do this as he was trained and stall the airplane, and the next thing we'll see is the imprint of an inverted aircraft that will kill everyone on board when it wasn't necessary.

We are very concerned about it. There are things that they do not know—the impact, the effect of heavy rain on the airfoil. As I pointed out, Dr. Houbolt of NASA has been cautioning about this

unequal spanwise distribution that will cause you to lose lateral control and is very critical at high angles of attack.

Do you know what a "stick shaker" is? I mean, maybe I didn't——

Mr. CARNEY. No; I don't, and I'm still trying to get that understanding. I'm not sure if everyone else in the audience might so, please, I beg——

Mr. MELVIN. It is a mechanical device that actually shakes the control column.

Mr. CARNEY. OK, but what are you doing with the attitude of the airplane, is what I'm trying to get.

Mr. MELVIN. Well, now, it's not attitude. It's angle of attack, and the angle of attack is the difference between the airfoil and the relative wind, which is not necessarily the attitude. If the relative wind is—the airplane is in level flight, that is, moving forward, then angle of attack and attitude are the same, but not at any other time—that is, if the airplane is climbing in a downdraft or descending in a downdraft, the pitch attitude will be entirely different than the angle of attack, and it's the angle of attack that causes the airplane to fly properly, that defines its flying quality.

Mr. CARNEY. So, what they are trying to recommend is that you put the aircraft in a higher angle of attack, getting near an angle that would stall the aircraft, to get through this particular weather problem.

Mr. MELVIN. Yes.

Mr. CARNEY. And what you are coming back to say is that there are too many variables involved: One, where is the plane, that type of thing; two, just how drastic is the weather situation?

What would your recommendation be? That the pilot be warned of this and he would know to respond as he flies through it, or what?

Mr. MELVIN. Well, first of all, he has inadequate instrumentation to do what is recommended. There is one recommendation—and I don't know where it is, it's in an advisory circular somewhere—one recommendation says that the pilot should fly the attitude that the "stick shaker" comes on at [illegible] that will not account for downdrafts and updrafts. That is, if the pilot flies into a downdraft and flies to the "stick shaker" and then exits the downdraft, the airplane is going to be in a full stall.

Another recommendation that appears in some literature is that the pilot watch the airspeed that the stick shaker comes on at and flies that airspeed. Well, the airspeed instrument is notably unreliable at those levels, plus the fact that if it were very reliable, it varies for the G-loading, and that does not account for differences in the G-loading, so they have given the pilot really a task that is very difficult to do.

They have an angle-of-attack sensor on the airplane, but the only thing it does is drive the "stick shaker" and it drives it only when it is down about 2 percent above the 1 G stall. Now what we are suggesting is that there be some optimum or some control strategy that says you reserve a certain amount of energy for the flare. We'll let the manufacturer decide that, but don't tell the pilots to go to the "stick shaker" when they are 300, 400, 500 feet in the air. The only question that we have had is timing. It's not that he

shouldn't do it. Certainly he should do it just before he hits the ground, but we really question that it should be done way up in the air.

Mr. CARNEY. That much I understand. Again, I appreciate your patience with me but I'm trying to get a better understanding of it.

How much would it cost to put the angle-of-attack instrumentation in the cockpit?

Mr. MELVIN. I don't know the cost, but the basic sensor, which is a vane on the side of the aircraft, and the computers and the things that process the information, are already parts of most transport-category aircraft. Of course, if it says "airplane" on it, it's very expensive, so my idea of what it ought to cost and what it will cost would be very different.

Mr. CARNEY. You did mention that you thought it would not be that expensive, a relatively inexpensive modification, since transport aircraft use the angle-of-attack sensor to activate the "stick shaker." What I was trying to get out of that is, basically you're saying most of this hardware would be available on a transport aircraft. It's a matter of maybe software additions or something like that.

Mr. MELVIN. It's a matter of putting a gauge there to read it and possibly changing the gauge that's there now, but——

Mr. CARNEY. And you do not agree with the FAA's reservation against making the angle-of-attack instrument mandatory?

Mr. MELVIN. No, we do not agree with that. We think, the Air Line Pilots Association has recommended angle-of-attack instrumentation for many years.

Mr. CARNEY. Well, given what we have in today's technology and given what we have in today's budget arena, what would you recommend we do as quickly as possible? Today, what type of recommendations could you make that would help alleviate some of these problems?

Mr. MELVIN. Immediately we would like to see microburst forecasting. The last time we testified before this committee on this subject, we gave recommendations of levels. We are not particularly in love with those levels but as long as there is some forecast, "Microburst is a probability today at Memphis," say, that alerts all those pilots flying into Memphis to look for some other tangible evidence of microburst. It can be a pilot report or a tower report or any other thing that says, "Yes, we have it." I think that would be an immediate thing that could be done today.

Mr. CARNEY. Switching to another area of safety, what kind of wind-shear training are airline pilots receiving now?

Mr. MELVIN. It's varied. Frankly, not all airlines agree, and some airlines have trained in simulator models. They are very poor models of wind shear, and the meetings that I attend, the management people admit that, that these models are not good models of wind shear.

A lot of the training, though, is sort of like training people to avoid shark bite. They are teaching people how to get their foot out of the shark's mouth, instead of get out of the water with the shark. There has been an underemphasis on how serious these things are, and the pilots who have sometimes trained in certain models and have learned to fly those models come out with su-

preme self-confidence that they have no problem with these things now because they have demonstrated their ability in the simulator with this particular model, not realizing that the microburst will exceed their capability and their aircraft's capability.

Mr. CARNEY. Again, then, it just gets down to having the techniques available to warn of impending possibilities of microburst and to avoid the microburst.

Mr. MELVIN. That's the best, the absolute best.

Mr. CARNEY. That's the ultimate way of handling the situation.

I would ask one final question. I don't know if you are in a position to answer it or not, but I know you said you didn't read the article on the Detroit scenario, and I'm certainly not going to sit here in judgment of that. I'm not capable and it's not fair to those involved but the one thing that did come to my attention, having nothing to do with the individual aircraft, was the fact that it seemed to me that, having I believe it was 16 or 19 transmissions from the air traffic controller in 1 minute, is an awful lot of communications going back and forth to aircraft in the area. Is that too much for a pilot in the cockpit to safely deal with?

Mr. MELVIN. It's too much to put anything—in other words, to have a dialog with the controller as to what the real situation is. You just can't get a word in edgewise, and that is a serious problem with communications in the terminal area: the manner in which the communications are conducted and the priorities. A lot could be helped with a data link, and there are certain simple devices that could be used. We had recommended one time before that the FAA adopt a technique that is used by NASA, and that is an end-of-message beep. A lot of times you find yourself on the radio and the guy that you just talked to—you thought he was through but he's not, and you end up talking at the same time. You've got to repeat the conversation.

A "busy" signal, for instance—you call the controller and he's busy talking to somebody else, he hears your transmission but you don't hear him respond back, so instead you come back again right on top of his next transmission and he has to get back again, and now you do it over and over—whereas if he could give you a little "beep, beep" or something, he heard your transmission, "Just wait and I'll get to you in a minute." That's all you need to know.

There are devices—I recently saw one—that computer process the signal that's coming in and when you start to key your mike, if a broadcast that's coming in that's just a microsecond ahead of your transmission, it will not let your mike key. Instead you will hear, you will receive instead—and you can override that—but there are some solutions that could be used today to help alleviate that.

Mr. CARNEY. To clean up some of that?

Mr. MELVIN. Right.

Mr. CARNEY. Finally, along those lines—and again, you might not be in a position to want to answer this question, and it has nothing to do with microburst, but in hearings that this committee has had we time and time again find that the airlines, to accommodate the demand of the consumer, crowd the schedule in certain areas and then at other times of the day there is very little traffic. Do you think that this situation is creating a danger at these major

hubs where there is so much traffic coming in and going out at one time?

Mr. MELVIN. Well, generally, again, the crew wants to carry the ball just like everybody else does. You're getting in line and other people are making successful takeoffs and landings, and so it's normal to you to just get in line and do that. There has to be something to ring the bell or a flag to say, "Hey, we've got a situation here that's different," to ring that alarm and say what the risk is now.

Now personally I have never experienced pressure from my airline management to push in areas that I thought were unsafe. I have never had my judgment questioned on that, if I have diverted or gone to another airport or refused to make a landing or a takeoff, and I think that responsible airline managements would not engage in that.

We do have a problem with some airlines that would push their pilots, that might not have facilities at brand X airport over here in case the pilot diverts to that airport. They don't have any gate facilities or anybody to handle it, and they really push their pilots to do that, and that is certainly feasible.

One of the things, though, that I do consider most important in avoiding microburst encounters are pilot reports, and I want to caution against intimidation against pilots to make these reports which can occur because of certificate action against pilots who have made mistakes. The guy takes off and he almost crashes, and he calls back and says, "Hey, I almost crashed. Don't let the next guy take off." The FAA might come in and file a violation on it. That type of activity—and I'm not sure that they're doing it, and I don't want to accuse the FAA of this, now—but that type of mentality and activity has hurt us before and could dramatically hurt us now, if pilots feel intimidated against making safety reports.

Mr. CARNEY. That has been brought to this committee's attention time and time again by your organization and others, and I think that the FAA, as you say, is aware of that and they are trying to have an open dialog so everybody benefits from it.

Captain, I certainly appreciate your testimony. It was very, very informative. I still don't understand completely the aerodynamics of the aircraft in these situations. Maybe sometime we could sit down for 5 or 10 minutes. I cannot hold up the rest of this committee hearing. We have a list of witnesses that have been very patient but we appreciate your testimony. Thank you.

Our next witness will be Dr. John W. Townsend, who is the president of Fairchild Space Co. and the chairman of the Committee on Low-Altitude Wind Shear and Its Hazard to Aviation for the National Academy of Science. Dr. Townsend, welcome.

Dr. TOWNSEND. Thank you, Mr. Chairman.

Mr. CARNEY. I happened to be watching the expressions on people in the audience, and you are telegraphing your approval and disapproval of every witness here, which tells me at least you are listening.

Dr. TOWNSEND. Oh, yes.

Mr. Chairman, perhaps in view of the time element this morning, and given that our report was published last September, with your permission I would like to submit my written testimony for

the record and just simply cover a few high points that strike me, and then I would be pleased to answer questions.

Mr. CARNEY. Without objection, that would be done. We do have a copy of the report as well up here, and that will be submitted for the record as well, and I appreciate your doing just that.

STATEMENT OF DR. JOHN W. TOWNSEND, JR., PRESIDENT, FAIRCHILD SPACE CO. AND CHAIRMAN, COMMITTEE ON LOW ALTITUDE WIND SHEAR AND ITS HAZARD TO AVIATION, NATIONAL ACADEMY OF SCIENCES

Dr. TOWNSEND. All right, sir. I would like to point out that it was the congressional concern over the accident in New Orleans that resulted in the establishment of my committee. The FAA was directed to enter into a contract with the Academy of Sciences and they, in turn, through their operational arm, the National Research Council, brought together the committee that I chaired to study this problem.

I would like to give credit to Ken Holtby, who is a senior vice president of the Boeing Co., who handled the aircraft part of this problem, and Dr. Louis Battan, who is a professor of meteorology at the University of Arizona, who chaired the meteorological aspects.

This was somewhat of an unusual study because it covered two commissions in the National Research Council, and we felt that because of the nature of the particular problem that we needed to cover both meteorology and aircraft and their performance.

We have heard a lot this morning about microbursts. They are clearly the most dangerous type of wind shear that we are dealing with at the present time, dangerous because we don't know all that there is to know and that we need to know about them—they have just recently been identified. And, second, there is a lack of awareness on the part of many pilots as to how dangerous these things can be.

I would like to point out, though, there are many different types of low-altitude wind shear that the report covers in some detail.

I would like to make a couple of comments. There are wind shears, and certainly in the case of microbursts, that no aircraft can penetrate safely if it's at a low altitude. We should recognize this. I certainly agree with what Bill said: Stay out, that's the first rule, because the devices we have available now on aircraft or could make available on all aircraft relatively quickly, only help you when you're in it, and of course at that time it may well be too late. So, although I don't want to minimize the necessity to make use of all instrumentation available, that is secondary to trying to avoid wind shear in the first place.

I would like to make one other point about the LLWAS system. It certainly is the system that's available today. It needs to be installed at more airports and it can be improved. However, it will never be installed at all airports so we have a class of activity that will probably never see an LLWAS nor see a microwave doppler radar in the future.

The only way out of that problem and perhaps the best solution is the airborne detector. The unfortunate thing is, we don't have a

good one at the present time, and that's why the committee said, in effect, there is no single solution to this problem. I say "have" it in the sense of full technological capability and economics; size, weight, power, and cost, all of those things which are so very important.

You have asked a number of questions this morning about what people should do right now. I would like to emphasize education and training. I think that's a key matter. Education—what is the problem here, what are we dealing with? Education in what types of meteorological conditions you are liable to encounter shear, creating an awareness on the part of the pilot that this is a serious problem.

For example, the committee very quickly found out that there is a feeling among many general aviation pilots that their airplanes are not subject to wind shear. "It's a swept-wing jet phenomenon," is the way you hear it. This is simply not true. It turns out that fortunately many of the general aviation airplanes have a fairly high thrust-to-weight ratio and, as the report explains, some of them may be better able to deal with wind shear, depending on the conditions, altitude, et cetera; however, they are affected, and this is one of the myths that we have to dispel with education.

The second thing is training. Bill stressed it. We should get good simulation models in simulators and conduct training on a very urgent basis.

I think that we have made a number of valid recommendations in our report, as you know, divided into things we should do right now and then in the midterm, as we put it, and then somewhere out at the end of what probably is a decade when we hopefully will have terminal dopplers in many of our airports. I would be glad to answer any questions along those lines.

[The prepared statement of Dr. Townsend follows:]

TESTIMONY OF DR. JOHN W. TOWNSEND, JR.
WIND SHEAR DETECTION TECHNOLOGY
JULY 25, 1984

Mr. Chairman, it is a pleasure to review briefly for you today the principal results of a study conducted last summer on the phenomena of low-altitude wind shears and their hazard to aviation. The study resulted from Congressional concern over the crash of a Pan American World Airways Boeing 727 minutes after takeoff from New Orleans International airport on July 9, 1982. Because of this concern, legislation was passed in December of 1982 requiring the FAA to enter into an agreement with the National Academy of Sciences to conduct a study through its operational arm, the National Research Council. I chaired the committee charged with this task, ably aided by Kenneth F. Holtby, Senior Vice President of the Boeing Company, who chaired a panel on aircraft performance and operations, and Dr. Louis J. Battan, Professor, Institute of Atmospheric Physics, University of Arizona, who chaired a panel on the meteorological aspects of low-altitude wind variability.

Although our report addresses a number of different types of low-altitude wind shear, my remarks today will highlight the relatively recently identified, and potentially dangerous, "microburst" and the hazard it poses to aircraft.

Microbursts are convective storm downdrafts that are unusually small in horizontal cross section and are generally of very short duration. When meteorological conditions are right for the formation of these often severe but localized events, columns of air moving down can strike the ground and spread out suddenly and sometimes violently in a shallow layer in such a way that an aircraft landing or taking off into a microburst will first experience a strong head wind, then a downdraft, and finally a strong tailwind. We call this passing through a wind shear. What happens then depends on the velocity of the aircraft, the velocity of the winds on either side of the shear, and on the height of the aircraft.

The committee's principal finding confirmed that low-altitude wind shear presents an infrequent but highly significant hazard to aircraft in the taking off or landing phases of flight. In the case of the microburst, wind shear that resulted from the strongest microbursts actually measured during a field experiment in the summer of 1982 in Denver could not have been penetrated safely by an aircraft if encountered below 300-500 feet of altitude. Simply stated, this means that the aircraft would crash. Obviously if a pilot is aware of the presence of strong wind shear, he should not take off or attempt a landing.

Fortunately, because of the small size, transient duration, and occurrence rate of microbursts, it is a relatively rare event when an aircraft encounters one near its active runway.

In addition to reviewing the state of knowledge of low-altitude wind shear and studying its effects on aircraft, my committee was charged with recommending actions to reduce the hazards of encounters and to improve flight safety. In our report we have divided these recommendations into those that can be made effective in the near term (one to three years), in the medium term (three to five years), and in the long term out to 10 years.

I would now like to give you the committee's recommendations, grouped roughly into the three time phases. The numbering does not indicate priority. It should also be noted that many of the longer term recommendations should be acted on and started in the near term--the grouping indicates when the desired result should be achieved.

Near Term Actions
General

1. Need For an Integrated Wind-Shear Program

To provide for the safety of the flying public, the FAA and the aviation industry should address the many facets of the low-altitude wind-shear problem as a whole. The FAA should develop and implement a coherent and sustained program for coping with the educational, meteorological, technological, and operational aspects of low-altitude wind-shear hazards.

2. Wind-Shear Education Program

The FAA and the industry should prepare and disseminate as widely as possible updated and authoritative information on wind shear. Informational materials should stress avoidance of wind shear and should describe flight control techniques for recovery from encounters. The information should encompass all types of aircraft, with appropriate guidance for each class. It should include recommendations on the most effective means of training pilots.

The FAA should revise and update its 1979 advisory circular (AC 00-50A) on wind shear and the Airman's Information Manual (AIM) to present the latest information, including detection techniques, alerting and warning procedures, effects of wind shear on aircraft performance, and procedures for recovery from wind-shear encounters.

3. Pilot/Controller Communications

The FAA should promote the use of standardized terminology and improved communications between flight crews and control towers. A standardized system of pilot reports (PIREPs) should be developed for reporting low-altitude wind-shear encounters. PIREPs should be mandatory and should include a report of the location, severity, and nature of the shear encountered--in consistent, standardized terminology. Controllers should communicate such reports to all flight crews in the vicinity. In addition, techniques for the direct broadcast to pilots of wind-shear data from the Low-Level Wind Shear Alert System (LLWSAS) or other sensors should be investigated.

4. Wind-Shear Detection System Development

The FAA should select a site to test direct and remote-sensing techniques in a complete system for detecting low-altitude wind shear and for providing information to pilots and controllers and to test the use of the information in the air traffic control system. The test site should be at a major airport where wind shear conditions are relatively frequent.

Detection and Prediction

5. The Low-Level Wind Shear Alert System (LLWSAS)

LLWSAS is the only system available in the near term for detecting low-altitude wind shear on an operational basis and every effort should be made to assess and improve its performance. Opportunities include, but are not limited to, better signal processing, reduced spacing between and increased number of sensors, improved sensor response and improved wind-display techniques and criteria for issuing wind-shear warnings, and the possible use of ground-based pressure sensors to augment LLWSAS information. An improved LLWSAS system is being developed for installation at New Orleans International Airport. This upgraded system, to be operationally tested in early 1984, should provide the basis for modification of current LLWSAS installations and for improved system performance for future installations. Depending on the New Orleans test results, the FAA should modify existing LLWSAS systems and install improved systems at all high-traffic density airports with terminal automation systems (153 airports) where there is likelihood of the occurrence of dangerous wind shears.

6. Record and Analyze LLWSAS Data

LLWSAS wind measurements should be recorded and analyzed to evaluate the system's performance and to learn more about the climatic properties of low-altitude wind shear. This should be done at all airports equipped with LLWSAS.

7. Use of Available Radar Data

The existing network of weather radars, operated by the National Weather Service (NWS), should be used more effectively to judge the likelihood of wind-shear conditions. These radars detect rain showers, thunderstorms, and phenomena often associated with wind shear. Information from weather radars should be made available to air traffic controllers in a timely and easily understandable fashion.

8. Airborne Remote Sensors

Research should continue on the use of airborne Doppler lidars and microwave Doppler radars as a means for detecting low-altitude wind shear.

Aircraft Performance and Operations

9. Wind-Shear Effects on Flight Characteristics

The FAA should sponsor analytical and simulator investigations to determine:

- The wind-shear penetration and recovery capabilities of transport aircraft, based on various onboard detection, guidance, and control systems.
- The effects of wind shear on various typical categories of general aviation aircraft and helicopters so that authoritative information on their response characteristics and piloting techniques in wind shear can be provided.

10. Aircraft Operating Procedures

The FAA should ensure that air carriers and other commercial operators instruct flight crews on what to do if they inadvertently encounter a low-altitude wind shear during takeoff or landing. In addition, the FAA should encourage operators of jet aircraft to incorporate in their manuals the operating procedures recommended in its advisory circular on wind shear. Aircraft manufacturers should recommend configuration-change sequences (gear, flaps, power, spoilers, etc.) that provide the highest probability for recovery from a wind shear encounter. Pilots should be taught to exceed the normal maximum thrust limits and to go to emergency thrust when necessary.

11. Wind-Shear Simulation Training

The FAA and the industry should cooperate to investigate new and innovative ways to make available the best possible simulation training for wind shear to the largest possible number of pilots, including general aviation pilots.

Research

12. Effects of Heavy Rain

Investigations should continue on how heavy rain affects the low-speed aerodynamic characteristics of aircraft. Particular attention should be paid to the possible adverse effects of heavy rain on aircraft lift, performance, and controllability, including its effects on wind-shear detection and flight sensor systems.

Medium Term Actions
Detection and Prediction

13. Next Generation Weather Radar (NEXRAD)

The next generation Doppler weather radar system (NEXRAD) should be developed and installed with all possible speed. This long-range radar system will serve many national needs related to severe-weather

detection, forecasting, and warning. For aviation the NEXRAD system can be used to detect and monitor weather situations along flight routes and, if located at or near some airports, to detect low-altitude wind shear or its precursors. Moreover, the Doppler radar will advance the rate of development of radar techniques for the detection of low-altitude wind shear and the development of dedicated Doppler terminal radars.

Aircraft Performance and Operations

14. Guidance and Control Aids

Onboard sensors and guidance aids should be evaluated in a systematic manner to determine their merits for future development and for possible retrofit in existing aircraft. These include flight director modifications, ground speed/airspeed flight management systems, vertical-acceleration sensors, and energy-rate sensors. Angle-of-attack indicators should be added to the cockpit instrumentation of transport aircraft for use in maneuvering through wind shears. Angle of attack should be provided either as a separate variable or as an input to other command displays. Sensors should provide flight crews with a voice warning of a hazardous wind shear.

15. Standardization of Wind-Shear Models

The FAA should sponsor a program to develop and define standardized models of wind shear based on the latest meteorological data. These models are required for design and certification of aircraft subsystems and for use in training simulators. The FAA should include other government agencies, aircraft manufacturers, commercial operators, and any other interested parties in the program.

16. Certification of Onboard Systems

The FAA should update its certification requirements for airborne wind-shear alerting, flight guidance, and automatic control systems.

Research

17. The Nature of Low-Altitude Wind Shear

More must be learned about the various kinds of wind shear and the meteorological conditions that cause or are associated with them. This knowledge is needed to reduce the hazards represented by low-altitude wind shear. Research should include additional field observations and the construction of theoretical models over the relevant scales--from about 1,000 feet to 10-20 miles and from minutes to hours.

The existing body of data obtained by various research programs should be reexamined and augmented, at an appropriate time, by a field program in the humid southeastern United States. Analyses of

the data obtained from the JAWS Project should be used to plan any new field investigation. Basic research into the origins of strong thunderstorm downdrafts and possible forecast methods should be an important component of any new program.

Long Term Actions
Detection and Prediction

18. Airport Terminal Weather Radar

The FAA should take immediate action to develop a pulsed Doppler radar system that can be used to observe weather conditions at and around airport terminals. This terminal radar system should be able to operate with a high degree of automation and to provide information on low-altitude wind shear, turbulence, and rainfall intensity. Such a radar must be capable of supplying information updated each minute and must have such features as ground-clutter cancellation and adequate spatial resolution.

19. Use of Airport Terminal Weather Radar Observations

For terminal Doppler radar to be most useful to traffic controllers and pilots, a concerted effort should be devoted to developing procedures for analyzing, displaying, and using its observations.

Mr. Chairman, I would like to close my statement today by emphasizing the crucial nature of education and training in the prevention of disasters. My committee felt that there was too little awareness of the dangers of wind shear and the critical need for avoidance on the part of pilots, particularly in general aviation. In fact, some pilots believe that small planes are not affected by wind shear -- but they are! We also felt that present procedures to recover from a shear encounter need improvement and then wide dissemination. To underline the validity of these needs, I would like to observe that there have been two serious incidents recently involving close calls to commercial airliners, one at Denver and one at Detroit, under conditions which make wind shear a prime suspect. If this turns out to be the case, we are not moving fast enough to reduce the level of hazard from low-altitude wind shear.

Thank you, Mr. Chairman

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Short Biography of John W. Townsend, Jr.

Dr. John W. Townsend, Jr., is a Vice President of Fairchild Industries, President of the Fairchild Space Company, and President and CEO of the Fairchild Space Operations Company. He was born in Washington, D.C., and attended Williams College where he received a BA in 1947, an MA in 1949, and a ScD (Hon.) in 1961 in Physics. During World War II he served as an officer in the Army Air Forces for over three years.

Dr. Townsend began his career at the Naval Research Laboratory in 1949 as a research physicist instrumenting V-2, Viking and Aerobee sounding rockets for upper air research. When NASA was created in 1958, he transferred with his Branch and the Vanguard Project, into the new Agency, becoming Chief of its Space Science Division. He was named Assistant Director, Space Science and Satellite Applications, of the NASA Goddard Space Flight Center in 1959, and Deputy Director in 1965.

In 1968, Dr. Townsend was appointed Deputy Administrator of the Environmental Science Services Administration in the Department of Commerce by President Johnson. Under a reorganization plan in 1970, this Agency became part of the National Oceanic and Atmospheric Administration (NOAA) and Dr. Townsend was appointed Associate Administrator by President Nixon. He ended thirty years of Federal Service in January of 1977. Since that time he has been employed by Fairchild Industries.

Dr. Townsend received the Navy's Meritorious Civilian Service Award in 1957, NASA's Medal for Outstanding Leadership in 1962, the Arthur S. Flemming Award in 1963, and the NASA Distinguished Service Medal in 1971.

Dr. Townsend is a member of the National Academy of Engineering and the International Academy of Astronautics. He is a Fellow of three professional societies, a member of three others, and has published a number of papers and articles. He is currently a member of the Space Applications Board, the Board on Atmospheric Sciences and Climate, and the Committee on NASA Program Changes, all of the National Research Council.

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Mr. CARNEY. Well, thank you very much.

Are you satisfied with the FAA's response to the recommendations that your panel has made?

Dr. TOWNSEND. Yes. I read their responses. I have a good deal of sympathy for the FAA because this problem and the fire problem happened almost simultaneously, and it does take time to set these kinds of situations under control. In some cases solutions are expensive; in other cases you do have to go through a formality of review within Government and within industry, et cetera

I think my general summary would be that they are now quite concerned and are doing things as rapidly as possible. I talked with John McCarthy, who is a member of one of our panels and who was the principal experimenter or one of the principal investigators in the JAWS, and found that he is quite pleased with the work they are doing under FAA sponsorship right now out in Denver, where they are essentially trying to make a real time system using the doppler and the LLWAS data. So I guess on balance the answer is yes.

Mr. CARNEY. Good.

Dr. TOWNSEND. Some things I am not happy with. Just like Bill, I do not understand why we don't put angle of attack in the cockpit. I'm an old pilot and I know some young military fighters who wouldn't fly without angle of attack indication. We even have it on our own corporate prop jet. You know, it's right up there in front of you where it can be a very valuable input to fly airplanes on. That one I just don't understand.

Mr. CARNEY. That will be duly noted.

What was the most critical of the recommendations? You talked about training. What was the most critical of the recommendations you made in the report?

Dr. TOWNSEND. Well, in the near term I think education and training are the most critical——

Mr. CARNEY. As you stated.

Dr. TOWNSEND [continuing]. But it's a combination. It's both education—you know, what the phenomenon is—and then training, both how to avoid it and, if you're caught, what to do, so that's a mixture.

Mr. CARNEY. Right.

Dr. TOWNSEND. Now there were some other very important recommendations that I don't mean to downgrade, for example, this question of communications between the pilot and the controller, and the passing on of pilot reports concerning wind shear in a more standardized format. That could be done almost immediately, making PIREPS of wind shear mandatory and straightening out the terminology, which you have heard a discussion of in the Detroit case this morning, so that it's clear to everybody that we've got wind shear and not just simply a shifting wind on the runway.

Mr. CARNEY. You said in your testimony here that we do have the technology. Certainly it can be improved but obviously it's not going to be implemented in all airports in our country. Do you feel that there is in the—I don't want to say near term—but there is a capability in the community to design the type of package that you would like to see, the airborne type of package, in the next—say by the end of the century?

Dr. TOWNSEND. Yes, by the end of the century I think we'll have it.

Mr. CARNEY. And you would have met the criteria you spoke of, weight and——

Dr. TOWNSEND. I do. Those criteria, Mr. Chairman, have to be of two types. One, the device has to do the technological job that it's supposed to accomplish. That is, it must in this case indicate well ahead of the position of the airplane the presence of a wind shear. It has to do so very reliably and without a lot of false alarms. If there are false alarms in the system, people begin to ignore it. It's the—you've heard some pilots, probably, tell you about the "pull up" announcements. Well, every now and then that system goes off so that it's annoying, and it's a little bit like crying "wolf," you know, so you don't want any false alarms with a system like that.

You also need a system that can fit into the fairly crammed environment of a modern cockpit—that means size and weight are critical. It can't be a power hog, and in terms of cost it must be reasonable. I liked Bill's comment about, "If it's got 'airplane' marked on it, it's expensive." There's a certain amount of truth to that, but even something that costs $10,000—which to some people seems like a lot of money, but in the aviation business it probably isn't—you must remember it is going to be on a fleet of aircraft, so you have to multiply that $10,000 by a fairly significant number of airplanes, and then you have to provide for the cost of installation, calibration, and down time. So the final cost may be large and significant.

Mr. CARNEY. Well, I think when it comes to safety devices that have been proven, the airlines and everyone cooperates in that area, and we recognize that there are those expenses associated with that. But there is one final question I have of you, Doctor, and that is when you put this additional information in the cockpit, are we going to take something else out? Aren't we at a point now, in today's cockpit anyhow, where the pilot and crew are so overburdened with data and dials and indicators and that it's sometimes difficult for them to absorb all the information that we're technically capable of spewing out?

Dr. TOWNSEND. Well, fortunately modern technology is coming to our aid there, too. There are some military aircraft flying now with completely all digital systems, where you just have cathode ray tube displays and not all those dials. Certain things are displayed all the time. The pilot can call up others at appropriate times.

The systems that Collins has built that are in the new Boeing aircraft are digital. They are what we call multiplex bus sytems and they, too, go a long way toward eliminating that clutter in the cockpit. Now those systems are expensive. If they are built into the airplane originally it's one thing, but if you had to face retrofitting with a whole modern avionics suite, that's a very, very expensive proposition.

My answer is that yes, I think it does add one more thing but at the same time we're getting other technologies that may make it possible for us to present more information to the pilot instead of a lot of data. There's a big difference, you know. You've got a whole bunch of dials there, all of which are sitting in the green line. You know, the information is, "don't worry." The data are all there but

you don't really care about the data; what you need is the information, and you find a lot of aircraft instruments are there because under certain conditions you may desperately need them but normally you don't, so the things you need right here and now are not all that large in number.

There is a true story about how you flew an airplane in the old days, which was on needle, ball, and airspeed. There were a lot of pilots who thought that's all the information you ever needed.

Mr. CARNEY. Well, doctor, I would like to thank you not only for your testimony today, but I would also like to thank you on behalf of the committee for the job that you did chairing your committee and the important work that the committee has produced. I'm hoping and I'm also encouraged with the answers that you have given us as to the response from the agencies involved. I'm hoping that we will put some of these recommendations together to improve the safety of our airspace. Thank you again.

Dr. TOWNSEND. Thank you, Mr. Chairman.

Mr. CARNEY. I love that "Mr. Chairman." I think we should have a vote on that right now. [Laughter.]

Our next witness is Peter Kuhn, Dr. Kuhn—pardon me—atmospheric physicist and consultant. Dr. Kuhn, did I pronounce that right? Kuhn?

Dr. KUHN. That's right.

Mr. CARNEY. Thank you, Doctor. Thank you for your patience.

Dr. KUHN. Mr. Chairman, since I have a statement that is filed with you and that is rather extensive——

Mr. CARNEY. It will be submitted for the record.

STATEMENT OF DR. PETER M. KUHN, ATMOSPHERIC PHYSICIST AND CONSULTANT, BOULDER, CO

Dr. KUHN. Following Dr. Townsend's lead, I would like to sort of—I would use the term "wing it"—as far as today, and I do have some slides because I think the operation that I would describe, this passive airborne detection system, is not too well known. It's a rather small program, thankful to NASA for the support, and now we're carrying it on a little bit on our own.

Just as I get into this I would say, also in agreement with Dr. Townsend, this is a device to detect wind shear that may not always be part of a downburst, and it is airborne. I am thinking of the many airports, as certainly he has and many others, that will possibly never have the more elaborate systems—say Milwaukee and Madison, and Chadron and Grand Island, NE. There are planes going in there. In fact, United, I talked to Captain Simmon day before yesterday, and United now flies nonstop Denver to Madison. He cited an incident at old Truax Field there at Madison on one of their flights where they ran into a gust front situation. It's a fine airport, but Madison is not Denver, it's not Atlanta, it's not Chicago, Los Angeles, Kennedy, or what not.

So the program started on the concept that if we could put something on an aircraft and look at a gust front, and this schematic drawing is nothing elaborate, but at least it indicates the point, we are looking at detection before one is into the situation. In other words, FAA had a circular—I've forgotten the number—about a

year ago where they stressed several points, but one of them was that research should continue on detection and avoidance.

A comment, again, on Captain Simmon, who is the flight training manager at Denver for United Air Lines—and Captain King and several others of United that we have worked with, in fact, flown with, would agree—if a commercial airliner could have perhaps 30 seconds warning—now we worked with a little device that would give 2½ miles, which is a little more than that at 12 feet per second, 3 degree and 150 knot approach—it would be out about a minute, 50 to 55 seconds. He indicated that if he could have 30 seconds, then with the training program that United now has—and he invited me to attend one of their sessions next week—they could avoid wind shear by the techniques that Captain Melvin and others and of course Dr. Townsend know, they could avoid this.

So we had talked to Captain Simmon and Captain King a year ago, or over a year ago, almost 2 years ago, and began this program of flying an infrared passive detector which as a second-order derivative determines not the wind speed but from early work—and I will go to the next slide—determines the existence of a shear condition, either part of a gust front or this happened to be a downburst. Well, I would like not to get into a discussion on downbursts and gust fronts and whether they are associated. I am thinking at the moment of thunderstorm density currents that come down out of an active thunderstorm area and produce strong either crosswinds or a loss of airspeed or a vertical sheer, per second.

This happened to be out of the JAWS system, and we were operating a B–57B, from NASA Ames and supported by Dr. Tobiason of NASA headquarters here, the funding for it.

I will keep saying "next slide." Just to keep this moving.

Now some early work was done by Fawbush and Miller many years ago out at Tinker Air Force Base, relating temperature and gust fronts. I'm speaking of a gust front, and I'm not denying that it couldn't be done with the present technology on a downburst. There is a question, and I am not at this point willing to say that we can't detect this. In fact, I have some staff people and colleagues here that might indicate that later on.

All right. The temperature difference between the environment and the gust front is given on the abscissa, and the ordinate is the gust itself in meters per second. Two and a quarter times that gives miles per hour, so if we had a 10 degree temperature difference, which this infrared sensor measures out ahead of the aircraft by using suitable filters in the carbon dioxide band of the atmosphere. That's the air temperature band. The satellites all use this for soundings and so forth. We look at it horizontally—if you had 10 degrees centigrade between the environment and the temperature at the aircraft—you have the Rosemont probe or whatever at the aircraft, you have this forward-looking instrument that you will shortly see—we would have 75 knots, which is quite excessive. One or two degrees difference sensed ahead of the aircraft—2 miles, 3 miles, 4, or back in shorter as Captain Simmon has suggested—will indicate the strength of the gust, the gust front.

There is another question on the downburst, and I would address that a little later.

This work was recently completed and I don't want to go into, waste your time on technical graphs that appear in publications—but in any event Dr. Freeman Hall and Dr. Caracena at NOAA in Boulder and working in the JAWS Program also verified that the temperature differences for a gust front will indicate the vertical shear—and he has got this in terms of per second, I could put that into perspective and say it's the number of knots per 100 feet, the shear in knots per 100 feet. What I am using this slide for is to say that very recent work in the last 2 years has confirmed the work that Fawbush and Miller did. Basically, they said with a gust front there is a temperature difference across the gust front, and the temperature difference is proportional to the strength of the outflowing thunderstorm density current which produces the shear. In fact, you have stood in waterfall winds, I am sure. It doesn't have to be Denver, it could be Madison, for that matter. And you know the cool outflow that comes out of a gust front. This is basic atmospheric physics.

Next slide, please.

So the procedure, without going into detail, on this graph display's the portion of the atmospheric spectrum indicated by wave numbers simply, which is one over the wave length, against the absorption in this band that we use to detect the temperature out ahead of the aircraft and then decide whether there is shear and where it is, absorption on the ordinate, wave number on the abscissa, in the middle of the graph which is termed the Q branch of the carbon dioxide atmospheric spectrum. You would have very strong absorption. If you picked a filter that could look there you might only see 100 meters ahead of the aircraft. If you go to the left or right flank you can increase the distance at sea level or at Denver's altitude out as far as 5, 6, 7 miles or 5 or 6 kilometers. That was just an example.

Next slide. Now formulas I don't want. Just the bottom one with the little triangle. The weighting function, which tells you how far you can see in the infrared—all of this work begs upon the work that is done by the satellite personnel. That final little formula, the k is the absorption coefficient for carbon dioxide. With no further reference to formulas and so forth, it was based upon that concept, added to what Fawbush and Miller and Caracena and Dr. Hall have done, that we proceeded as in the next slide, and we will go ahead.

The idea was to use a sensor that could see temperature differences ahead of the aircraft and compare it with the nearer. The first plan and the first work was done on NASA Ames' Lear 24, with a radiometer as in the next slide. Oh, the radiometer is a simple device, not elaborate, and really 15-year-old technology. There are people here today from Hughes Aircraft who know that this technology has been surpassed, that the accuracy of measuring that temperature 2 to 3 miles ahead of the aircraft has increased now from perhaps one degree with this device down to a tenth of the degree in the next. It's a simple device, infrared passive, no forward beam or anything at all, not dependent upon radar.

The next slide, please. Just NASA's good old 705 over Monterey Bay. The next, please, will indicate the mounting.

The red circle on the nose was our first concept, the first thing that was put on the Ames 24 Lear, and we flew with NASA's test pilots—Fulton, who flies the shuttle recovery, and Fred Drinkwater, and many others, Bob Innes, all NASA test pilots. This is bulky, and when we talked to Clark Benson at United, up at Boeing, and he looked through all of this the comment was, "Well, we can't stick something like that on an aircraft," so we went to the next approach and the next slide. I am moving along.

This was a simple little light pipe with a 45 degree angle, gold-coated mirror, stuck somewhere on the aircraft. It's actually in this case 7 inches minus 1 because the 1 inch is up above, 6 inches long, and can be rotated to almost any position, and in the next slide I will indicate the position we used on NASA's CV-990, the Convair 990. This was just for convenience and expense. We are glad for the funds we had but we couldn't go into an elaborate puncturing of the aircraft at this stage, and so it was placed on the port side of the aircraft up near the entrance, just behind, I think that's the Quantas symbol, I can't remember, we had been in Australia on some flights in the Southern Hemisphere. Incidentally, the instrument works on CAT and low-altitude wind shear. There is a Federal patent that's available in the public domain on the CAT point.

The next slide moved over to NASA's B-57B, and you can slip to the next because I'm sure most people know of that aircraft. The next slide, please.

All right. This was the mounting that took NASA Dryden oh, about, I would say 3 hours to get onto the aircraft, by their engineering department. The radiometer is inside. The data in this case was put on magnetic tape, and this was used in the JAWS experiment and has been evaluated over the year, and we got a large collection of data out of Oklahoma City on heavy rain. There are arguments on infrared—can you see into a rain, a heavy rain? Now a light rain, or virga, as I think Captain Melvin has mentioned. We can get through that. The satellite people are doing that today in sounders over the ocean and we are using their techniques.

The software, I won't go into the processesing of signal, will either display in contours on the weather radar or we will have another little meter. NASA Ames had suggested a small meter and perhaps a chime or something. That's loading up the cockpit. I know what you're saying, but I have talked to the pilots out there and there are many other ways it can be shared on another instrument.

We are coming slowly to the results. Next slide.

Now this is just another indication of where it is mounted. It's very straightforward, no problems on it. I talked to Clark Benson, United, and Captain Simmon, and also to the Air Guard at Denver, and they want try this out on a 737—I think that's a T-43A trainer—in the same area, on a baggage compartment door. It's not complicated.

All right. The next slide, please.

Now into the results, and in this case we have an approach and I will give the abscissas and ordinates. On the left ordinate in the lower case is the temperature differential that we measure, and that is indicated by the middle curve, and it is indicated in a temperature of zero on the line at about two-thirds of the way down

the graph. I want to do this quickly for you. This is exact JAWS data. It happened to be on of July 15, 1982. The upper is the altitude of the aircraft given in thousands of feet, 5 and 6 at the top. The abscissa is "time before encounter."

Now this was done as follows: The B–57B flew with Mr. Fulton, the NASA test pilot, and a rear observer. We couldn't go into the back end. I couldn't. I have flown on all their other planes and I'm oxygen qualified but not ejection seat qualified, so NASA had another pilot in the rear seat.

The data was presented to them as well as on magnetic tape. The concept is right there. The aircraft up above is approaching on a track angle of 271 degrees, from the right on the screen to the left. Those are the actual winds measured on the aircraft as it approached. You can see they are 225 from the southwest in general until a sharp break to the northwest as this thunderstorm density current and associated gust front came through up to 35 knots. This was done on an Apple because of economy. We didn't use the Cyber 150–700 there at the Bureau of Standards at Denver, but the Apple is very good for plotting and can handle tapes. You can convert the NASA tape over to Apple disks. Apple is fine. I don't sell them, but they are good.

Now the approach. The time is given before the encounter, taking the middle curve, at approximately 60 seconds as a drop in temperature of greater than 1°C per second from the aircraft, which is still several seconds—in this case about 40—away from what the lower curve shows. And the lower curve with that little pyramid on the left, its ordinate is on the right side of the graph and it is the vector difference magnitude of the wind, and I just say a north wind at 20 abruptly becoming a south wind at 20 is a vector difference magnitude of 40 knots. Now this wasn't north and south, and the trigonometry that goes into this is relatively simple to program.

All right. At about 12 seconds before the zero time on that graph, the vector difference magnitude reached 25 knots. At the same time, the crosswind component went from about 10 knots, 10 knots from the south, to a component of 30 knots from the north, so here you had 40 knots in a gust front. I have not said and would not identify a downburst at this point. That's what we want to continue to do.

All right, the next slide. I am only going to give a few of these.

Here is another approach, at 271 degrees. You can see the slope coming down from 5,600 feet on down to about 5,200. No landings were made. The same type of situation, a warning—an alert, if you wish—which can be processed in many ways, displayed on the weather radar screen. There are all kinds of techniques. We did not have money to do that, and I agree with Dr. Townsend that the technology for this infrared device is in a transfer stage now. It is not something. You could put it on a NASA jet but perhaps not on United's 727 out of San Diego for Denver, Milwaukee, and Baltimore.

But the alert did occur then, at about 40 to 45 seconds. The pyramid, lower left, lower curve—I'm sorry, the ordinate on the right—reached almost 40 knots, the vector wind difference magnitude in

this case. Then we'll go to the next slide, another case that isn't so nice. I mean, there were a lot of them that were rather poor.

A confusion of winds as the approach again was on 271 degrees, the west runway at Stapleton, and finally a sharp increase in wind at the end, but the alert and that's the middle curve—was a little more gradual. It took more time. It only gave about 30 seconds of warning in this case, and I should mention at Denver everything was done during JAWS, triggered by Dr. McCarthy or Caracena or others—there were many others—into situations that would most likely produce this type of situation.

It was mentioned earlier this morning and also by Captain Simmon, "How about flying it out somewhere where there is nothing, on the false alarm idea?" We did very well on getting them but they were all in good conditions, and I will go into that, that false alarm.

The next, please. Another one, this is an approach to the east, 90 degrees, and the same type of thing. The alert occurred to the left with that downward blip of 7 degrees and so forth, and then the triangle to the right is the actual encounter, about 30 knots of vector wind difference.

The next, please.

All right, now the results: Out of 42 cases—it's a poor histogram. I used a Nikon and a little breadboard or something, and I guess I'm not too good, but in any event the abscissa on the bottom is the alert time before an actual shear encounter in seconds, and the event frequency as a histogram is the lower ordinate, listed 5, 10, and 15 of these 42 cases, and then corresponding to the same time as the vector wind difference magnitude in knots started on the left upper ordinate, 0, 30, and 60.

OK. We considered everything a failure if we had 30 seconds or less warning. I would have to now revise that after talking to United Air Lines. They feel that 30 seconds, since almost all of their 300 jets can accelerate at 2 to 3 knots per second and he went through the ritual for me, that if he had a 30 knot vector difference magnitude and he had 30 seconds he could pick up 90 knots—well, it can be—perhaps 60 to 90 knots. All right. Our primary warning time was in the 40 to 50 seconds, of which there were 29 cases. We had—and in those cases directly above the two larger bar graphs in those cells for 40—actually that's 35 to 45 seconds, centered on 40, 45 to 55, centered on 50—the corresponding vector difference magnitude up above is anywhere from 30 to 38 knots for those encounters that were noted that far in advance. The failures now would be the ones, three of them, at only 10 seconds, so the score was still pretty good but it's biased toward only shear encounters—I'm sorry—to situations where there was shear. Out at National Airport today, or Denver this afternoon, hopefully, or evening when I get back, it may not be a shear situation. We want to find out about false alarms. We want it to go on. We do want to go on.

We have some indications—and I wouldn't quote—from Dr. Tobiason of NASA that further checks will be made on these three topics, and I will go to the next. It may show.

Yes. Now that same slide has a little drawing down there ahead of that aircraft in the lower left. It has some little contour lines,

range lines, and it also has two bands to the left and right that are scan lines. In other words, it is done mechanically—and this has already been fabricated up at Colorado State University. We are doing it on a rather tight budget, and we are doing a little flying in this high wing Cessna 207, with a little company. We put in about 1,000 to get $90-an-hour aircraft time and try this.

We bought four filters, they are pretty expensive, $500 apiece, that give the four or five different ranges, from 4 miles, 3 miles, 2 miles, and a half mile, and then a little wobbulator or whatever you want to call it that moves that little mirror to give us some scanning. So we have not done scanning, we have not done ranging, and a very critical point from Dr. Tobiason is rain.

Now we have tried, in Oklahoma. Will this thing work in any fashion at all as you are approaching a deluge? Well, I am not a pilot. I have flown millions of miles with the NASA gentlemen. I guess I wouldn't fly into a deluge, but what about moderate rain or spotty showers? We don't know. We have Oklahoma City data that is coming from a NASA experiment with the B-57, and then finally I believe it will be addressed. They will proceed with this program at NASA Langley. I think it was Dr.—I forgot his name—Houbolt.

I think that was—oh, yes. There are further statistics that I don't want to bore you with. I would rather answer questions if you have any. I have cited our feelings and I think I would terminate it on that, Mr. Chairman, and ask you if you have any questions.

[The prepared statement of Dr. Kuhn follows:]

STATEMENT OF TESTIMONY

U.S. HOUSE OF REPRESENTATIVES

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

25 July 1984

Peter M. Kuhn

The first nineteen pages of this statement of testimony before the subcommittee hearing on wind shear detection technology are a reproduction of an American Institute of Aeronautics and Astronautics manuscript, Log Number C5245, accepted for publication in the September, 1984, issue of the "Journal of Aircraft." The paper, Airborne Infrared Low Altitude Wind Shear Detection Test is authored by P.M.Kuhn and R.L.Kurkowski.

Additional comments and conclusions follow the reproduction of the manuscript.

AIRBORNE INFRARED LOW ALTITUDE WIND SHEAR DETECTION TEST

Peter M. Kuhn* and Richard L. Kurkowski**
NASA Ames Research Center, Moffett Field, California

Strong wind shears at low altitudes present severe hazards to aircraft during landing approach and takeoff. With aircraft operating near stall speed, a significant change in the wind speed and/or direction can result in a rapid loss or gain in altitude. Our objective is to describe the test of a prototype system for airborne, advance detection of such wind shear by means of infrared remote sensing. The test was conducted during the Denver Joint Airport Weather Studies (JAWS) project in the summer of 1982 aboard the NASA Ames B57B jet aircraft during several landing approaches and departures. The intent is to present analyses of the major results of this test and suggest its application to the passive, airborne detection of hazardous low altitude wind shear (LAWS) before an aircraft encounter. This is critical for aircraft operating in and out of airfields without LAWS ground warning systems. This airborne wind shear detection and avoidance system is intended to augment the advanced, ground-based microwave, lidar and low altitude wind shear alert equipment as a secondary, airborne system. Even at distances as great as 20 km (12.5) miles from thunderstorms, the wind shear in storm density currents can pose a real hazard to approaching and departing aircraft. It is concluded that the prototype airborne radiometer, sensing in the 13 to 16 micrometer portion of the atmospheric molecular spectrum of CO_2, can sense the cold current

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outflow or gust front directly associated with low altitude wind shear (LAWS) in the vicinity of thunderstorms at ranges up to four miles.

Nomenclature

cm	wavelength
Cp	specific heat at constant pressure, $m^2 s^{-2} K^{-1}$
du/dz	vertical shear, s^{-1} or knots/100 ft.
g	gravitational acceleration, ms^{-2}
N,B	radiance, w cm^{-2} sr^{-1}
K	temperature °K
k	CO_2 absorption coefficient, $cm^2 g^{-1}$
P	pressure, g $cm^{-1} s^{-2}$
q	mass mixing ratio of CO_2, g g^{-1}
R	gas constant, 2.87 x 10^6 cm^2 s^{-2} K^{-1}
T	temperature °C
u	optical thickness of CO_2 gas (g cm^{-2}), $q \frac{P}{RT} x$
x	horizontal distance, cm
z	vertical distance, m
$\Delta T/\Delta \tau$	forward looking IR air temperature minus static air
-	temperature at aircraft, °C s^{-1}
$\Delta \nu$	optical filter band width, cm^{-1}
θ	potential temperature (°K), T + gz/Cp
ν	wave number, cm^{-1}
τ	CO_2 transmission, %
ρ	air density, g cm^{-3}, P/RT
$\phi(\nu)$	radiometer filter transmission, %

Introduction

The physical basis for the IR temperature sensing wind shear predictor system is the demonstrated relationship between the temperature gradient from undisturbed air across a shear-producing gust-front or downburst outflow and the wind speed and direction of the gust front outflow wind. The higher temperature gradients produce higher wind shear or peak gusts. Fawbush and Miller[1] provided a physical basis for predicting peak gusts caused by thunderstorm density currents. Temperature drops of 5C may readily produce peak gusts of 35 miles per hour while those of 15C produce peak gusts of 80 miles per hour (Fig. 1). The IR radiometer senses the cold outflow of the gust front downdraft well before the aircraft encounters the region. The precision of the IR radiometer is ± 0.5C, allowing for consecutive observations sampled at a 0.5 Hz rate to vary by only ± 0.5C. Signal integration will, of course, provide a standard error as low as ± 0.1C. Shear alerts occur when a defined temperature difference between this "forward" IR air temperature and the ambient air temperature at the aircraft, defined as a threshold criterion of -0.5C/sec, is reached or exceeded. Alternatively the "forward" air temperature may be converted to potential temperature, θ, which is essentially constant during landing and takeoff in a neutrally stratified atmospheric layer. If negative anomalies exist in th. profile of θ which exceed a defined value, these can also be the basis of LAWS alerts aboard the aircraft. The "forward" air temperature minus the "near"

air temperature at the aircraft provides a temperature difference change per second $\Delta T / \Delta t$. This change is then compared with the shear test criterion to initiate a shear warning if warranted (Fig. 2). The criterion to warn of potential shear is a negative 0.5C/sec or greater temperature change. As the temperature difference per second increases, the algorithm applied to the radiometer output predicts gust front shear to also increase. The operation of a similar IR airborne system has been described by Kuhn, et al.[2]

In a horizontally uniform temperature field both the near filter channel of the radiometer or the static air temperature measured at the aircraft and the forward, long range sensing filter channel of the radiometer sense the same temperature. As a cool outflow gust-front is approached, the long range channel begins to sense a cooler temperature well before the aircraft reaches the gust front, and the near channel senses the warmer static temperature at the aircraft until the cool downdraft or gust front is penetrated. At this point both radiometers sense the same temperature for a period of time. No alert for LLWS is produced until the temperature difference beween the forward sensed temperature and the aircraft temperature reaches the pre-determined negative threshold. Alert conditions are, of course, continuously upgraded. The precision of the forward sensing radiometer filter combination is approximately 0.5C, as previously noted.

Radiation Physics

The width of the IR radiometer filter pass band, $\delta\nu$, is an important consideration in designing the optics of the IR LLWS radiometer (Caracena, et al.).[3] Theoretical considerations show that narrow pass bands give the best spatial discrimination of thermal perturbations, while broad pass bands produce the strongest corresponding perturbation signal in the radiometer output.

Radiation in the atmospheric molecular spectrum of carbon dioxide reaching the radiometer optics may be expressed as

$$\tilde{N} = -\int_{\nu}\int_{x} B(\nu,T)\phi(\nu)\left(\frac{\partial\tau\,(u[CO_2])}{\partial x}\right) dx d\nu \qquad (1)$$

In Eq. (1) the horizontal transmission may be expressed as

$$\tau_{\Delta\nu} = \exp(-k_{\Delta\nu} q\rho x) \qquad (2)$$

where the product, $q\rho$, is the density of carbon dioxide gas. The horizontal "look-distance" or weighting function distance in Eq. (1) is given by $\delta\tau/\delta\ell nx$ as a function of the horizontal path distance, x. Eq. (2) may be differentiated with respect to distance, x, to give,

$$\frac{\delta\tau}{\delta\ell nx} = -k_{\Delta\nu} q\rho\tau x \qquad (3)$$

An evaluation of Eq. (3) as a function of various horizontal distances, x, and altitudes (33 to 490 m) over various pass bands at 10 cm^{-1} intervals in the 600 to 710 cm^{-1} portion of the CO_2 spectrum resulted in the best weighting function or look-distance centered at

695 cm^{-1} providing a horizontal look-distance of 5 km (2.9 miles). This would give approximately 70 seconds warning time to shear encounter.

Data Acquisition and Processing

The NASA Dryden B57B aircraft was the landing-approach platform for the IR LAWS sensor system during JAWS.[4] This fully instrumented gust gradient aircraft, carrying an elaborate data acquisition system and the IR sensor, among many other instruments, provided time, latitude, longitude, track angle, heading, altitude, static air temperature, E-W wind speed, N-S wind speed and airspeed for the airborne IR study. The IR LAWS optics appears in figure 3 as the probe just off of an instrument access hatch on the starboard side, forward of the wing root section. Adjustable optics allow for horizontal leveling of the "look" angle.

Data tapes were processed via a Cyber 150-700 and Apple II Plus to obtain the final high resolution graphic plots that appear in figures 4 through 9. Algorithms to compute all the approach data for the wind speed and direction arrows, altitude, vector difference magnitude, ΔT threshold, cross wind to aircraft track component, vertical shear, and aircraft horizontal and vertical position enabled the figures to be computer-generated via appropriate algorithms directly from original NASA tapes.

Each flight track figure displays the following:

The date and run number are shown.

The time before touchdown is given in seconds as abscissa.

The lower left ordinate is ΔT in °C (Shear alert threshold)

The upper left ordinate is altitude in kilo-feet.

The right ordinate is the vector difference magnitude in knots.

The lowest computer-plotted curve is the vector difference magnitude.

The middle computer plotted curve is ΔT(°C) (Shear threshold) tracing about zero. Negative ΔT defines a colder forward temperature.

The top side of the figure is north with the other directions as on any map. Thus a landing approach at 270° would be depicted from right (east) to left (west).

The top computer plotted curve is flight approach track with wind arrow flying into the curve. For example, a north wind comes from the top of figure onto curve while an east wind comes from right margin of figure into curve. Wind speeds and direction are standard meteorological station plots.

Each full feather or barb denotes a speed of 10 knots. A half barb denotes a speed of 5 knots and an open triangular feather, 50 knots.

Recall that ΔT is defined as the forward air temperature minus the aircraft ambient temperature. From this $\Delta T/\Delta t$ (°C/sec) is readily determined and compared with the shear-alert threshold of negative 0.5C/second. Post-flight analyses as in this test will be replaced by microprocessor-driven, alerting displays.

Shear Detection Measurements During JAWS

As a prologue to the discussion of the remote measurements during the JAWS Project[4] and their meaning, three observed phenomena resulting from wind shear, all or any of which can impair aircraft operations, are considered in each flight sequence. They are vertical shear, vector-difference magnitude and aircraft cross-wind component. This summary considers these meteorological phenomena that can be hazardous to aircraft operations. This low-altitude wind shear detection test offers advance determination of dangerous atmospheric conditions into which an aircraft may proceed.

Figures 4 through 9 graphically illustrate six NASA B57B approaches into shear conditions at Stapleton International Airport and the JAWS network in and near Denver in July of 1982. Table 1 and the figures (with standard aeronautical and meteorological symbols and nomenclature) summarize the analyses. A reference to the preceding section, "Data Acquisition and Processing," for the figure explanation is suggested.

In column 5 of Table 1, the radiometric advance alert during descent along the glide path is given as "t" minus some number of seconds. This is the time in seconds before touchdown, or simulated touchdown. Vertical shear, du/dz, columns eight and nine of the table, is given in units of sec^{-1} and knots per 100 meters. "-AS" indicates a loss of airspeed exceeding 30 knots.

Two of the flight approaches, runs 17 of the 14th and 15th of July (Figures 4 and 5), for NASA B57B, on-approach into Stapleton International on the 14th and 15th of July 1982 during JAWS

Table 1. Summary Analyses of Airborne Radiometric Shear Alert Episodes with Subsequent Approach Conditions Encountered

Figure	Date/Run No.	Aircraft Track Angle	Weather	Measured Shear Threshold Occurs at (seconds)[a]	Cross Wind Component (Knots)[b]	Vector Difference Magnitude (Knots)[c]	Vertical Shear du/dz (sec^{-1} & Knots/100 ft)		
4	7/15/82-17	271°	Light rain	t - 58	0 to S33	26	.33	20	-AS[d]
5	7/14/82-17	271°	Virga[e]	t - 43	S15 to S28	20	.16	10	
6	7/14/82-21	225°	Virga	t - 50	0 to S40	47	.16	10	-AS
7	7/15/82-10	45°	--	t - 64	0 to S11	34	.20	12	-AS
8	7/15/82-12	45°	--	t - 20	P24 to P3	47	.16	10	-AS
9	7/15/82-13	225°	--	t - 40	S36 to S25	36	.08	5	

[a] t minus seconds refers to time before touchdown.

[b] The S or P designates a starboard or port component.

[c] The vector difference magnitude is computed over a 10 second interval.

[d] -AS indicates air speed loss of 30 or more knots.

[e] Falling trails of precipitation.

illustrate encounters with strong vertical shear, du/dz, in the lower 100 m (503 feet) and the operation of the airborne IR LLWS instrument system preceding the encounter. Hall et al.[5] have provided experimental evidence of the relation between vertical wind shear du/dz and the temperature drop across a gust front or thunderstorm density current outflow. Figure 10 illustrates this relationship. The vertical shear may be expressed in knots (nautical miles per hour) per 100 feet or in inverse seconds (s^{-1}). This relation may be expressed as:

$$\frac{du}{dz}\left(\frac{\text{knots}}{100\ \text{ft}}\right) = \frac{\text{nautical mi}}{3600\ \text{seconds}} \times \frac{6020\ \text{feet}}{\text{nautical mi}} \times \frac{1}{100\ \text{ft}} = \frac{.01672}{\text{second}} \quad (4)$$

NASA JAWS Run 17 (Figure 4) is an approach in light rain on track, angle 271° with winds varying from 225° to 230° at 5 to 10 knots through 24 seconds prior to touchdown to 330° at 35 to 40 knots at 14 seconds before touchdown (BT). From the figure it is clear that at 58 seconds before touchdown (BT) the IR radiometer sensed the threshold of 0.5C/second indicating strong cool air outflow ahead. Light rain and virga does not appear to extinguish the signal from the cool outflow ahead. The vertical shear between 18 seconds and 13 seconds BT (as the aircraft descended 100 feet) was .15 sec^{-1} or 9 knots per 100 feet. Snyder[6] has shown that vertical shears greater than 0.1 sec^{-1} are hazardous to large, swept-wing, jet aircraft. The plotted run of figure 5 exhibits similar features and with a 43 second alert.

Abrupt changing cross winds normal to the flight approach track appear to present problems in the flight approach runs plotted in

figures 4, 6 and 8. The approaches from figures 4 and 6 evidenced a shear threshold at 58 and 50 seconds, some two to two and one-half miles before touchdown at altitudes of six to seven hundred feet. The onboard radiometer system did not provide sufficient advance alert to the cross wind shear in approach 10 plotted in figure 7.

Vector difference magnitudes occurring within a 10 second interval appeared potentially hazardous in the approaches computer plotted from the data of runs 10, 12 and 21 (Figs. 6, 7 and 8) of 15 July 1982. The vector difference magnitudes of 34 to 47 knots seemed large enough to suggest problems. There the radiometer system failed to provide sufficient advance warning of the ensuing shear encounter. However, of the six approaches into potential thunderstorm shear conditions, the system operated successfully five times with an average advance alert to following shear of 31 seconds before encounter.

We have summarized but six of 42 approaches or departures into potential shear conditions, with five detected successfully an average of 51 seconds before encounter. In one case (Fig. 8) advance detection was not successful. The success rate of 83% for the six events reviewed corresponds to a success rate of 35 advance detections out of the total 42 encounters.

Conclusions

The results of this airborne infrared low-level wind shear predictor system test provide an initial indication of the potential feasibility (83% success) of passive IR remote sensing of horizontal temperature gradients associated with shear producing gust fronts

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or thunderstorm density currents. During approach to touchdown alert times averaging 51 seconds correspond to approximately two miles out from touchdown and should thus provide sufficient time for a "go around" decision. The shear index ($\Delta T/\Delta t$), determined with a limited amount of sample data, is evidently related to the vertical shear, du/dz, the vector different magnitude and cross wind shear. The effects of "looking" through light rain or virga do not appear to pose a problem and are being studied further. Weighting function changes via different IR filters, ranging and azimuthal scanning can add to the potential usefulness of this passive IR airborne shear predictor system by providing increased range and avoidance possibilities.

Acknowledgment

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[2]Kuhn, P. M., Kurkowski, R. L., and Caracena, F., "Airborne Operation of an Infrared Low-level Wind Shear Prediction System," J. of Aircraft, Vol. 20, 1983, pp. 170-173.

[3]Caracena, F., Kuhn, P. M., and Kurkowski, R. L., "Design and Preliminary Tests of an IR-airborne LLWS Remote Sensing System," AIAA Paper 81-0239, January, 1981.

[4]The JAWS (Joint Airport Weather Studies) Project, Operations Summary 1982, National Center for Atmospheric Research, Boulder, CO and the University of Chicago, Chicago, Illinois, February 1983.

[5]Hall, F. F., Neff, W. D., and Frazier, T.V. "Wind Shear Observations in Thunderstorm Density Currents," Nature, Vol. 264, 1976, pp. 408-411.

[6]Snyder, C. T., "Analogue Study of Longitudinal Response to Wind Shear and Sustained Gusts During Landing Approach," NASA TN D-4447, NASA Ames Research Center, Moffett Field, CA 94035, 1968.

Figure Captions

Fig. 1 Outflow peak gust vs. temperature drop in thunderstorm.

Fig. 2 Airborne infrared low altitude wind shear detection system.

Fig. 3 Installation of infrared low altitude wind shear probe on NASA B57B.

Fig. 4 Computer reproduction of B57B approach on track angle 271°. Right ordinate is wind vector difference magnitude in knots; abscissa is seconds before touchdown; left lower ordinate is T(°C); left upper ordinate is altitude in kilofeet. See text for explanation of curves. Flight 7/15/82-17.

Fig. 5 Computer reproduction of B57B approach on track angle 271°. All labels as in Fig. 4. Flight 7/14/82-17

Fig. 6 Computer reproduction of B57B approach on track angle 225°. All labels as in Fig. 4. Flight 7/14/82-21

Fig. 7 Computer reproduction of B57B approach on track angle 45°. All labels as in Fig. 4. Flight 7/15/82-10

Fig. 8 Computer reproduction of B57B approach on track angle 45°. All labels as in Fig. 4. Flight 7/15/82-12

Fig. 9 Computer reproduction of B57B approach on track angle 225°. All labels as in Fig. 4. Flight 7/15/82-13

Fig. 10 Thunderstorm vertical shear (seconds^{-1}) vs. drop in temperature across gust front.

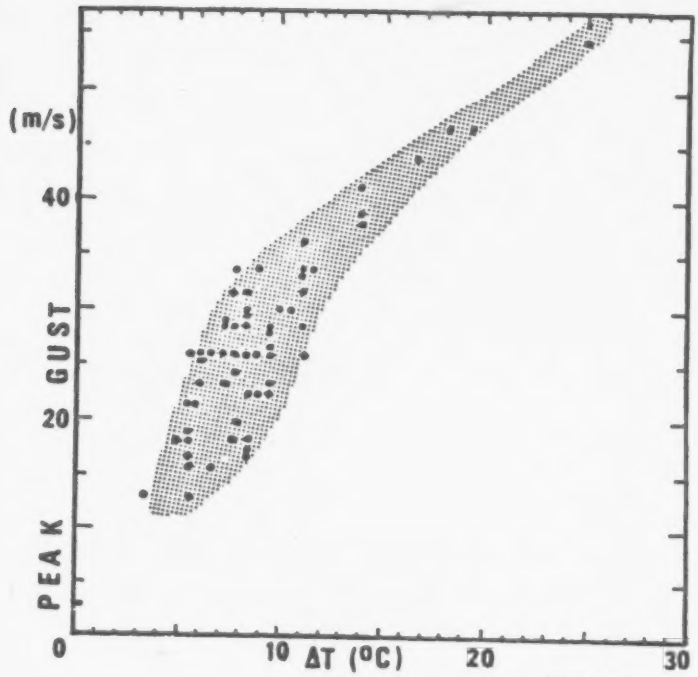


FIG. 1

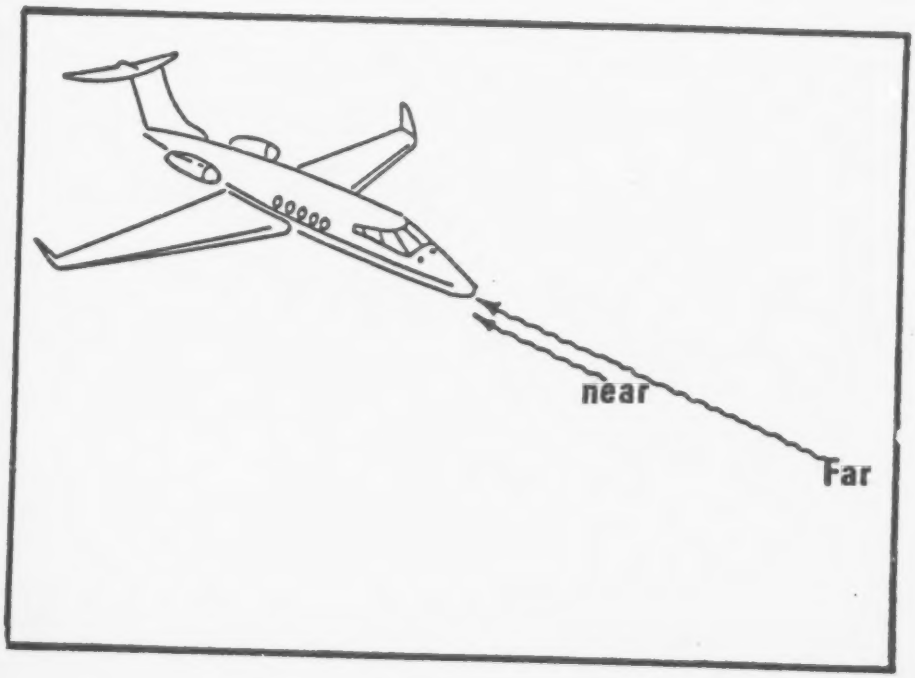
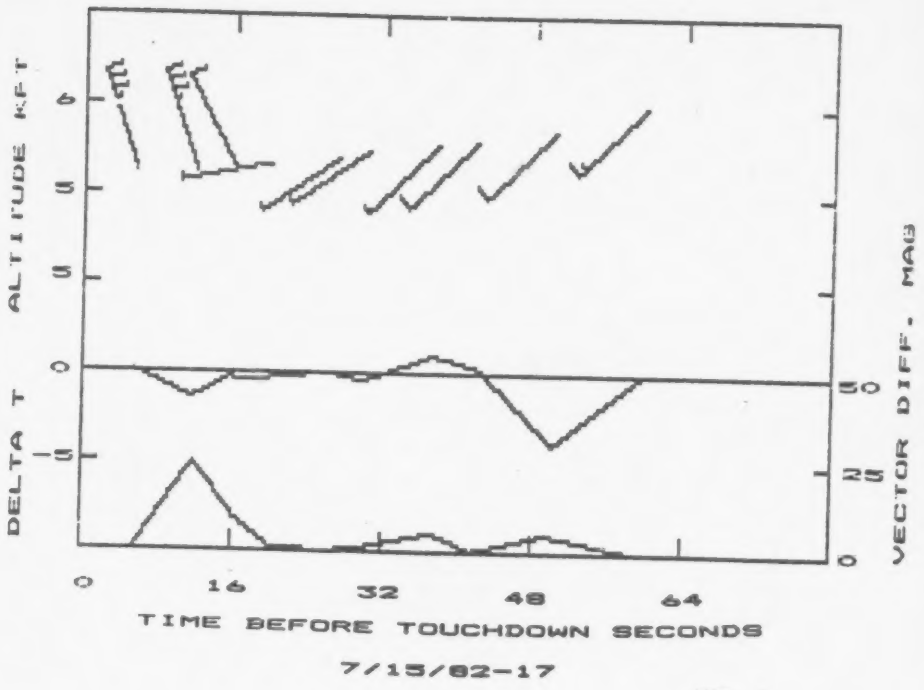


FIG. 2


DELTA T ALTITUDE KFT
6
5
0
-5
VECTOR DIFF. MAG
50
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32
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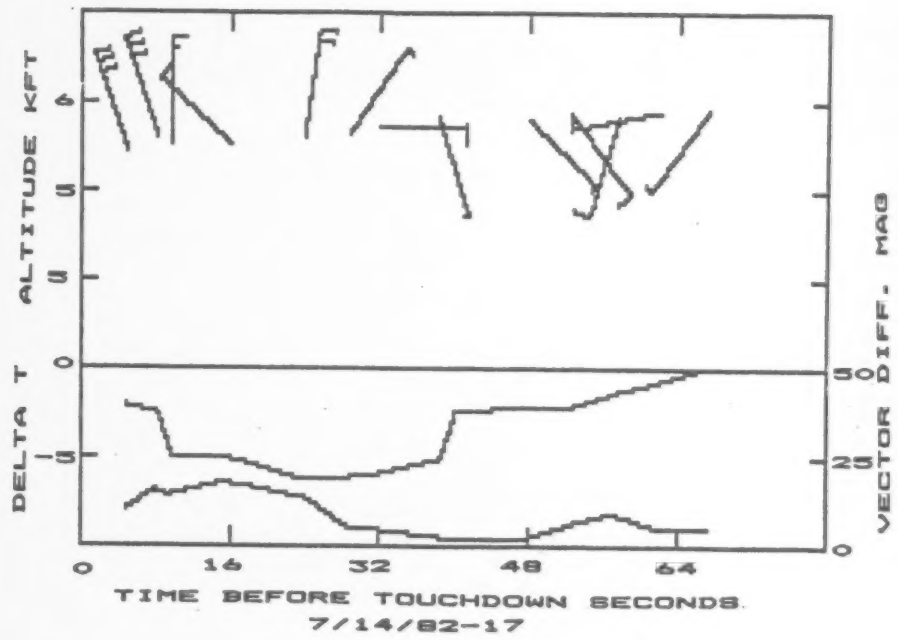
64
TIME BEFORE TOUCHDOWN SECONDS
7/15/82-17

FIG. 4


DELTA T ALTITUDE KFT
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16
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48
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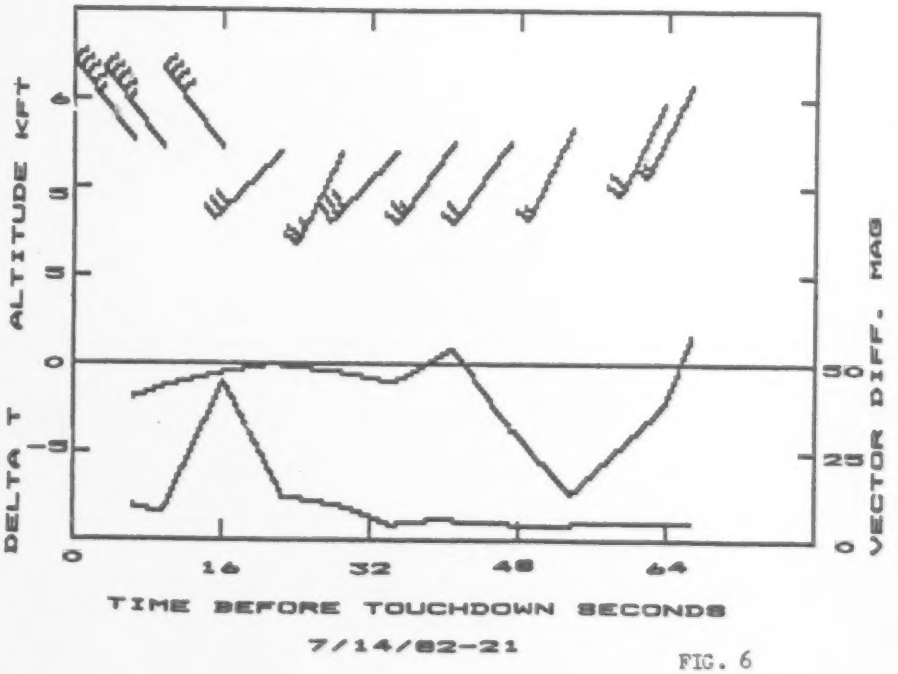
TIME BEFORE TOUCHDOWN SECONDS
7/14/82-17

FIG. 5


DELTA T ALTITUDE KFT
VECTOR DIFF. MAG
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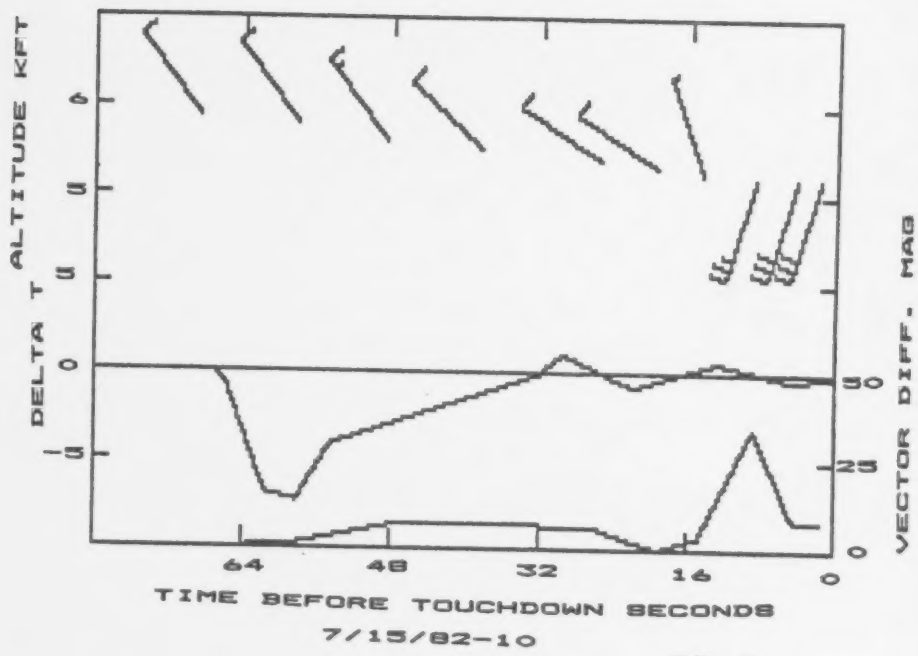
16
32
48
64
TIME BEFORE TOUCHDOWN SECONDS
7/14/82-21

FIG. 6


DELTA T ALTITUDE KFT
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4
2
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VECTOR DIFF. MAG
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16
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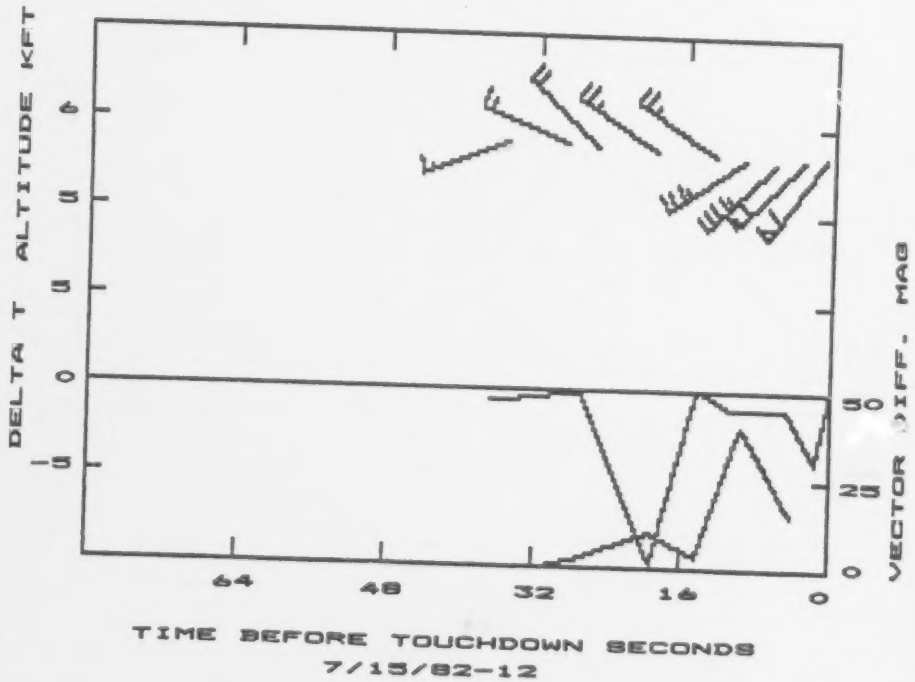
TIME BEFORE TOUCHDOWN SECONDS
7/15/82-10

FIG. 7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VECTOR DIFF. MAG
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64
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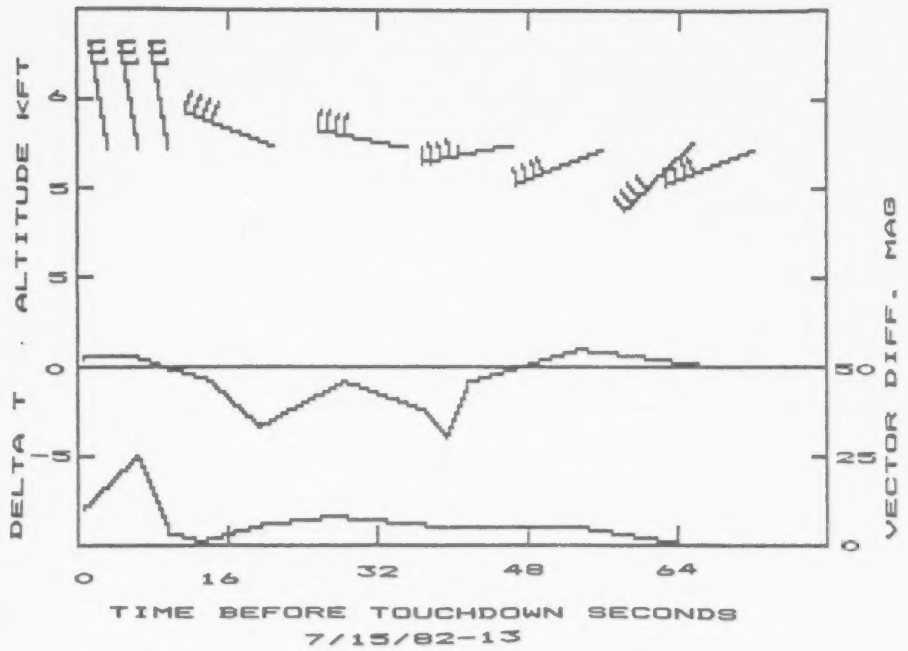
TIME BEFORE TOUCHDOWN SECONDS
7/15/82-12

FIG. 8


DELTA T . ALTITUDE KFT
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VECTOR DIFF. MAG
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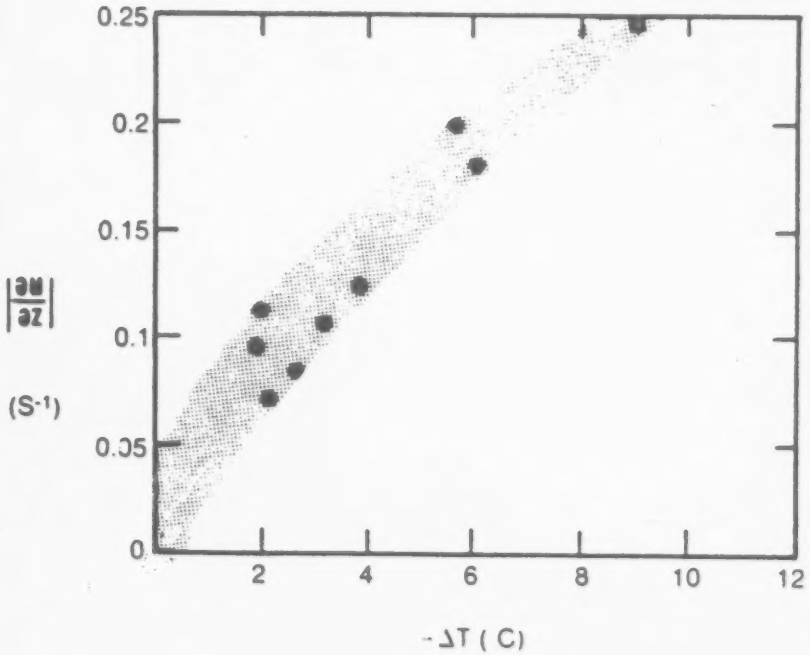
64
TIME BEFORE TOUCHDOWN SECONDS
7/15/82-13

FIG. 9


0.25
0.2
0.15
0.1
0.05
0
|∂w/∂z|
(S-1)
2
4
6
8
10
12
-ΔT (C)

Additional Comments and Conclusions

During the infrared, airborne wind shear prediction test forty-two wind shear encounters were identified as such from the B57B aircraft data tapes and pilot response. In all of these encounters the infrared airborne detection system was operational. These shear encounter episodes and the frequency of their pre-encounter detection in ten second interval cells (detection time before encounter) appear in Figure 11. Each histogram cell is ten seconds wide, centered on the even 10, 30, 40, 50 and 70 second advance detection time. Just above the frequency graph of pre-encounter detection time a mean wind vector difference magnitude in knots is plotted. The right hand tick mark on the vector difference bars is the standard deviation for the means. For example there occurred fifteen pre-encounter detection "alerts" thirty-five to forty-five seconds before these encounters. Of these fifteen "alerts" the subsequent shear encounters involved wind vector difference magnitudes averaging thirty-eight knots, apparently large enough to be potentially hazardous to approach or departure operations. Reference this figure, the eight 10 and 30 second pre-encounter detections were considered failures.

The evolution of mounting techniques for the infrared probe is evident in Figures 12 and 13. The original approach visualized a forward-looking, infrared transmitting (KRS-5) window through which signals would reach the detector. The present concept of a one inch diameter light pipe with a 45° angled mirror enables a much simpler installation virtually anywhere on the aircraft coupled with the possibility of horizontal scanning via rotation of the forward directed mirror.

The scanning and ranging concept for approach (or departure) is illustrated in Figure 14. Present infrared detectors and filters would certainly permit ranging and horizontal scanning in a variety of methods. CRT display technology could provide a countoured picture with possible shear intensity levels from the infrared detection system on the weather radar or a small adjunct display. This procedure should be further developed and pilot evaluated in a light aircraft such as a Cessna 207 or equivalent.

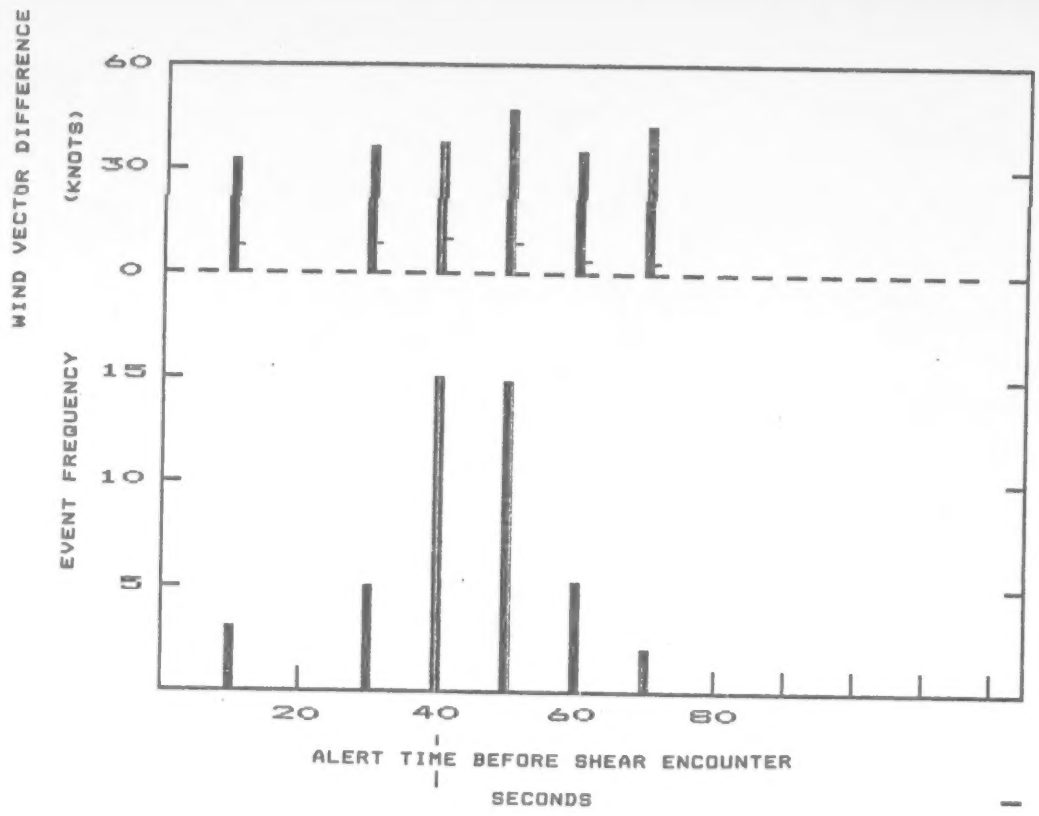


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Fig. 11

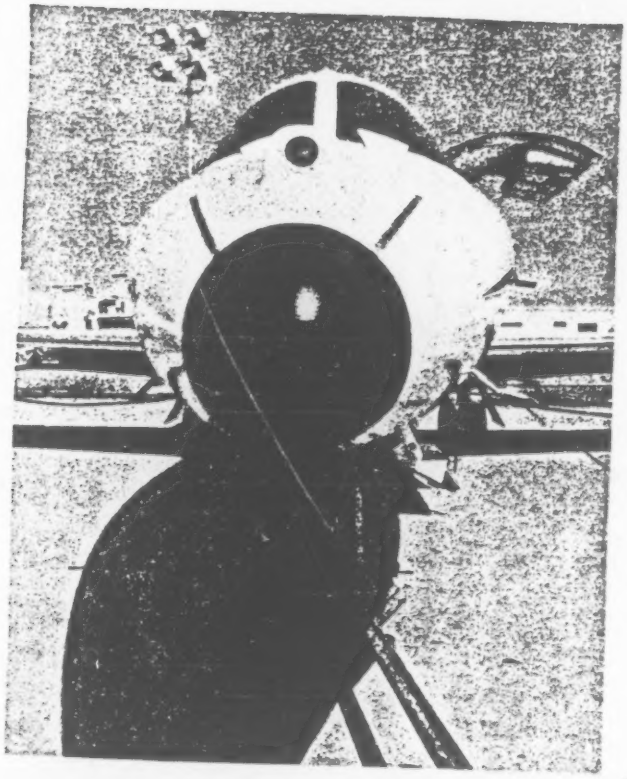

Fig. 12

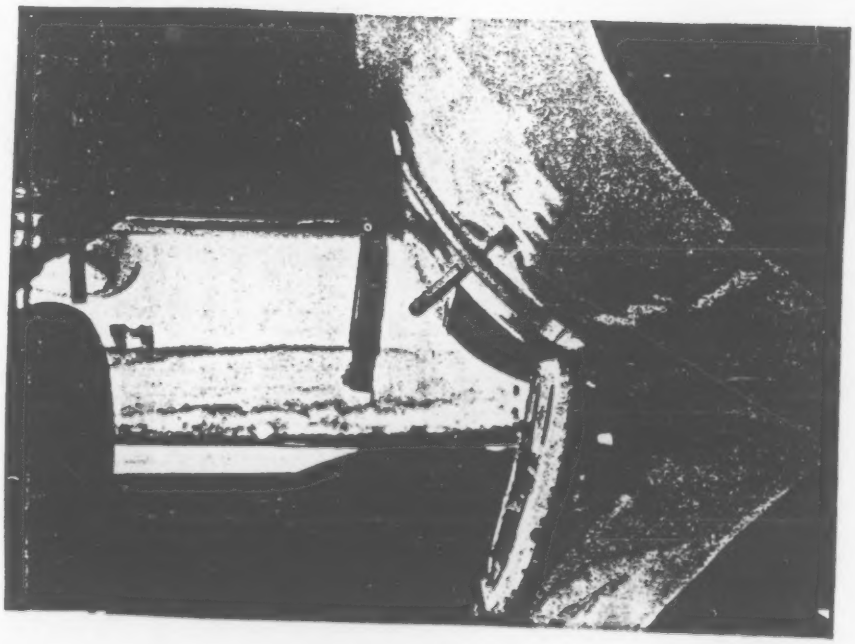

Fig. 13

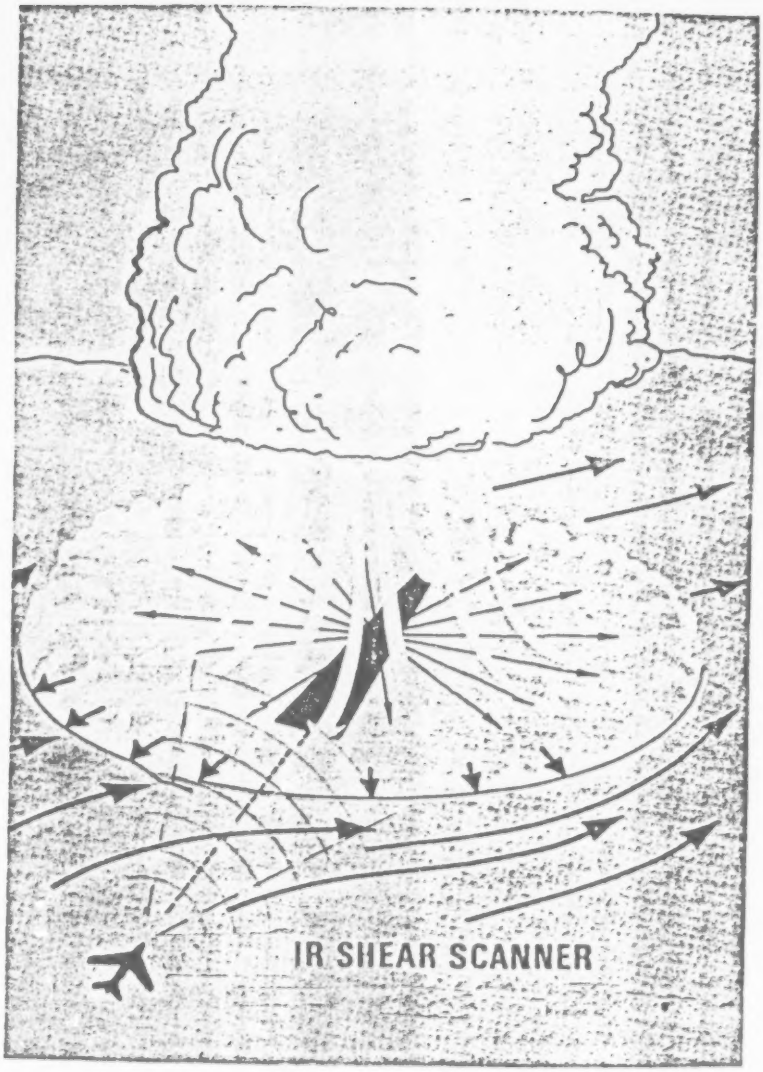

Fig. 14

Conclusions

When considering this infrared, airborne shear detection system one should note that it was only the second airborne test of the concept, the first of which aboard the NASA Ames Lear 25 operated on the cool sea breeze in the Bay Area to simulate gust fronts. The second test with the NASA B57B during JAWS at Denver in 1982 was carried out on a modest budget with re-furbished (15 year old) radiometers and but one available infrared filter limiting the forward shear alert time to a maximum of 50 to 60 seconds or approximately 2.0 to 2,5 miles out. This would correspond roughly to an approach altitude at alert of 600 to 700 feet during a 12 foot per second descent rate.

These comments are not meant to denigrate in any way the NASA support received as this was an initial test. It is, however, strongly believed by the writer and several others, in particular Dr. Fernando Caracena, a theoretician of the NOAA Boulder Laboratories experienced in the analysis and physical interpretation of wind shear, that further experimentation and testing could produce dramatic results employing this concept. Twelve months of research with current radiometric equipment and a selection of three or four infrared optical filters could determine, finally, the systems value in the airborne detection before encounter, ranging and scan avoidance of hazardous gust front wind shear and even imbeded "downbursts." The employment of a cost effective, meteorologically instrumented,available light aircraft would greatly reduce the cost of a final test flight series.

In conclusion, an FAA official whose name I fail to recall, stated at a Washington, DC meeting in March of 1983 with other NASA and FAA personnel and myself present that eighteen months of further experimentation could bring this airborne, infrared shear alert program to the point of final evaluation. Subsequently we asked for some $39000 but other more pressing budgetary problems did not make it possible to allocate the funds. For the last sixteen months a very limited program of data evaluation has kept the program alive. Currently I have with Dr. Peter C. Sinclair, ARIS, Inc., submitted a small business proposal for such a study under the NASA SBIR program. Presently, as a retired former Federal employee, I am engaged in consulting in atmospheric remote sensing with Aeromet, Inc., Teledyne-Brown Inc., ARIS, Inc., and research part-time for Northrop Services, Inc.

RESUME

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Boulder, CO 80302 — 9/52 - 5/80

Program Leader- GS - 15

Initiate, conduct and supervise research in remote sensing (infrared) of the atmosphere directed to the improvement of aviation safety and to improving forecasting by analysis of the energetics of the atmospheric radiation budget. Initiate and develop,via computer software, new approaches to the solution of problems in atmospheric radiative transfer through research in the infrared portion of the electromagnetic spectrum. From "in situ" observations of atmospheric absorption, transmission and emission the incumbent developed variants of the radiative transfer approximation in a radiative transfer model including cloud and aerosol effects as an input for numerical weather models. Conduct research in molecular radiometry, atmospheric gas emissivity and transmission including numerical analyses and program development. Incumbent prepared numerous scientific papers, technical raports and program review. He prepared formal, inter-agency proposals for funding support for his remote sensing and aviation safety technology research, primarily to the National Aeronautics and Space Agency.

Incumbent served as meteorologist and radiometer systems principal investigator for the Medium Altitude Missions Branch of NASA's Ames Research Center. He was thoroughly experienced in on-board, high-altitude airborne radiometry systems of the NASA Ames C-141A, U2, Learjet and Convair 990 jet airborne laboratories.
The incumbent supervised three employees, including one GS-13 professional, one GS-5 sub-professional and one GS-4 sub-professional.
The incumbent retired from the Federal Government on 28 February 1980 after thrity-one years of service.

Mr. CARNEY. Dr. Kuhn, I do have some questions but unfortunately the second bells have rung for a vote, and I will be back in about 5 minutes time if you could wait, and then we have one last panel of witnesses that would follow immediately. I will try to make it in about 5 minutes.

[A short recess was taken.]

Mr. CARNEY. We will bring the hearing back to order.

Doctor, again I apologize for having to leave to vote.

In your testimony you indicated that your research has shown a portential feasibility—with an 83 percent success rate, I might add—for the passive infrared remote sensing of temperature gradients associated with wind shear producing phenomena. To be sure I understand that correctly, are you saying that you are able to predict wind shears correctly 83 percent of the time?

Dr. KUHN. Out of the 42—to make sure I understand you—out of the 42 cases where there was an encounter, 83 percent of the time the infrared—poor little instrument, if you wish, passive instrument—did indicate a temperature difference from 50 to 30 seconds before the aircraft, continuing on its flight track, reached the actual shear sensed by both the pilot and the instruments on the aircraft.

Mr. CARNEY. What would you consider to be an adequate data base? Forty-two, I would think, would be somewhat small.

Dr. KUHN. Forty-two is not sufficient. It is a small data base. Of course, I would add that a B-57B, the old Canberra, is an expensive aircraft. The program, JAWS, was designed—the joint airport weather studies—so that we would get some time, thanks to Dr. Tobiason, but we weren't the sole experimenter, so the limited size is due to just the expenses involved. I certainly would like to obtain more data—we are trying a little 207 now between Denver and Fort Collins, after that American Airlines thing a week ago—what is it, 2 weeks ago—that went 6,000 feet off in the grass at Denver. It wasn't mentioned today. I guess it's rather new.

But it needs a larger data base. It needs at least the moral support of an agency that has much more experience than I do. I am now a retired Federal, so I don't have the funds—I'm not complaining. I have an excellent retirement. I'm not worried, but I can't conduct the research that large companies such as Hughes Aircraft, that might some day work in conjunction with NASA or FAA. I can merely consult. It needs a bigger data base.

Mr. CARNEY. Well, that's my next question: Is NASA interested in continuing this research, and is the private sector interested as well?

Dr. KUHN. I would have to answer affirmatively, yes. In discussions with Dr. Tobiason, who is present today—now I'm not telling you that it's on any enormous scale, but he has said that a program being set up at NASA Langley, and I think that was Dr. Houbolt, or I have forgotten it, the gentleman, the scientist who will take over the B-57 this fall—he has indicated to me, and he can state—if what I am saying is not correct—that they do intend to proceed, I guess I would like to say to the end, to finish out this infrared approach, so the answer to NASA is yes from what I understand.

The answer on industry is, there are colleagues—I am not an employee of Hughes Aircraft or Santa Barbara Research, I am a private consultant, but I do work, not for them but a little for Boeing, Teledyne, Brown, and others—Santa Barbara Research Center of Hughes Aircraft, and they are present today, are definitely interested in going ahead with this. The Boeing Corp., Clark Benson out of Renton, WA, has spoken with me in the last 3 weeks. United Air Lines—and Captain Simmon said anyone is free to contact him—I want to be very careful in this statement: He has said, "I am a pilot. I cannot fight my way through the garbage of communications on the ground." Now I'm speaking for him, and I'm not a pilot and he is.

Mr. CARNEY. Well, I think we addressed that all day long.

Dr. KUHN. Yes.

Mr. CARNEY. That seemed to be an underlying theme.

Dr. KUHN. He said, "I want 30 seconds in the cockpit. I will make room for the device if you can . . ."—of course, he didn't realize that I have no facility. I have to work with other people. He said, "If you can loan us a piece of equipment, we will stick it on a 727 out of San Jose to Baltimore-Friendship" or whatever you now call it, "and we have an instrumented aircraft. You will not have to put dials, tape recorders, or anything on it. I have a plane. Can you loan me an instrument?"

I said I have to go back to the technology point: Is the instrument ready to turn over to United Air Lines? Would it be that you've got to have some character riding on every flight? So that's what was discussed with Mr. Tobiason or Dr. Tobiason earlier today, and Mr. Weiss of Santa Barbara Research Center. Somebody has to make an instrument, and United will fly it. They will pay for the installation, and you have the word of this captain.

All right. That was your question. What was it? It was on industry and NASA.

Mr. CARNEY. You have answered the question rather adequately. Both NASA and industry are interested in a continuation of the research in this particular area, and from the demonstration that you provided with the slides it looks like a very simple type of thing to modify aircraft with. I am not familiar with the expenses of those types of infrared devices but it was small enough——

Dr. KUHN. Oh, yes. Well, the cost—oh, I'm sorry.

Mr. CARNEY. I'm sure it could start to fit into the pattern that the witness just before you described: Something that's airborne, doesn't take a lot of room, doesn't absorb a lot of power in the aircraft, and perhaps can be built at a cost that would encourage transport aircraft particularly to install these things.

Dr. KUHN. If you recall—and I think your statement on data base is extremely critical—that agrees with Dr. Tobiason. It needs, before you rush—not you but someone rushes—to United and says, "Here is the great fantasy. It's all over. Here."—that isn't the case and we wouldn't claim that, but we do think that if an instrument were built up, they would be very happy to fly, and who else to accumulate data than the man who is going to depend on it?

Its cost can run anywhere from—well, I just take a wild figure here, and it may not be agreed with in industry, and I am very poor at cost figures—$10 thousand. I think a tire on a DC-10—I'm

not sure—is some—well, all right. We're getting into the tires. But this doesn't count sticking it on the weather radar. There are red-hot hardware and software people that can move it over, and that's what NASA was going to do on the Lear, is use their RCA color weather radar and just stick this on, but we ran out of money, not through their fault or mine. We had a depression in the country, I believe, and that slowed everything down for a while.

Mr. CARNEY. Well, we have a hot economy now. We ought to be able to get some money to continue the program.

Well, Doctor, I appreciate your testimony and I appreciate the fact that you have been sitting and waiting to give it. I might add, too, that I certainly appreciate the enthusiasm in which you gave your testimony. I'm sure that enthusiasm goes into how you carried out the research data and I hope that, as you said, both industry and Government, particularly NASA, will continue to carry out this program. It could very well be the beginning of something that would answer the problems that are a very important problem of the wind shear phenomenon.

Dr. KUHN. Thank you, sir.

Mr. CARNEY. Our next witness is Mr. Neal A. Blake, the Deputy Associate Administrator for Engineering for the FAA, and he is accompanied by Kenneth S. Hunter, Director of the Office of Flight Operations, and Willard Reazin, Manager of the Procedures Division of the Air Traffic Service.

Mr. Reazin, you are a familiar face. You were at yesterday's panel as well. I hope we're not keeping you folks from your desks too much in your agencies, that you can't get any work done.

I would ask, if I may, Mr. Blake, I know you have a lengthy testimony and I would appreciate if you could just do an overview of your testimony. It will be entered in the record in its entirety. If you could just give us a summary of it and be available with your team for a couple of questions, I would appreciate it.

STATEMENT OF NEAL A. BLAKE, DEPUTY ASSOCIATE ADMINISTRATOR FOR ENGINEERING, FEDERAL AVIATION ADMINISTRATION, ACCOMPANIED BY KENNETH S. HUNT, DIRECTOR, OFFICE OF FLIGHT OPERATIONS; AND WILLARD REAZIN, MANAGER, PROCEDURES DIVISION OF THE AIR TRAFFIC SERVICE

Mr. BLAKE. Well, thank you, Mr. Chairman. I was going to suggest that, too, in the interest of time.

I think you are well aware that we have had a wind shear program underway since the early 1970's and that there have been a number of products that have come out of that program. Some of the areas that have been covered by the research are the characterization of wind shear, the definition of the hazard itself, improvements in wind shear forecasting, investigation and testing of wind shear detection techniques and equipments—and we're talking here both in the airplane and on the ground.

Through several research activities, piloted simulations, and so on, we have been developing both equipment and also procedures for use by the pilot, should he be unfortunate enough to become involved in a wind shear encounter. We have had the help of a number of people. One has been Dr. Theodore Fujita of the Univer-

sity of Chicago, who is one of the key figures in the joint airport weather studies and who is playing an instrumental part right now in our activity which will lead to improved forecasting of wind shear techiques.

The low-level wind shear alerting system was mentioned by several of the speakers today. We at the present time have 59 systems installed and operating. We plan to have another 51 installed by the end of next year and operating. In addition, we have expanded the system at New Orleans to add additional sensors and additional processing, and we are addressing a number of the suggestions which you heard made by various speakers earlier today. Some of those include the use of processing which would positively identify phenomena such as gust front passage and also microburst. We do not yet know the extent to which we can detect the microburst phenomenon completely with such a system, but we will be able to get the answer to that through our experimentation in the New Orleans test bed.

And of course we are very much interested in this program in being able to identify for the pilot the fact that there is a microburst at the airport, rather than that there is a 15-knot wind difference between the center of the runway and the beginning of the runway.

The committee in their letter asked about our plans with regard to the remote radar weather display system. We are in the process of implementing this at a number of our facilities, including the air traffic control facilities, the flight service station en route flight advisory positions, some of our high activity flight service stations, some weather service field offices. This system makes available to the FAA people the weather information from I believe it is 134 radars throughout the country. Some of those are FAA radars; some of those are National Weather Service radars.

The information is also made available at our center weather service units, and through those units information on severe weather formation and movement is passed directly to the tower and to the terminal facilities.

The next generation weather radar program was mentioned. This is, of course, a cooperative program with National Weather Service and the Department of Defense and, while it will provide us with a great deal of information on severe weather that we cannot get out of current weather radars and our own FAA radars, its ability to at the same time detect and present wind shear warnings while doing all of the other products and also looking out to quite a great distance, results in some compromise of the wind shear detection capability.

The NEXRAD Program is moving along well. The release for prototype construction was given this summer, and we expect to have those prototypes in December of 1985 and to start installing systems in 1988 through 1992. However, we believe that we need to go beyond the NEXRAD if we are really to do an effective job of wind shear detection in the terminal area, and we have been doing research and experimentation on the use of doppler weather radar with the National Severe Storms Laboratory for a number of years, and we have also had inputs from a number of other members of the scientific community.

I think that through the experiments that we have done—Project NIMROD in northern Illinois, the JAWS Program, and the Memphis Program which is starting this summer—we have gained a great deal of insight into the phenomenon itself and also into the capabilities of the doppler weather radar. In the past we have been using existing radars to examine weather in the Norman, OK, area. This summer for the first time we will be using a radar test bed at Memphis which has incorporated in it a great deal of what we have learned about doppler weather radar and, for the first time, includes some processing equipment to help us interpret the phenomena which the radar is looking at.

We will have two radars at the test bed. One is a C band radar which is brought to us by the University of North Dakota, and an S band radar which was put together by Lincoln Laboratory, and both of these radars will be operating in the Memphis area. We will also have a very extensive Mesonet. These are a series of small weather stations, if you will, that will be in the area which will allow us to plot the ground wind field and temperatures very accurately and to compare what can be measured on the ground with what is seen by the radars.

We will also have several research aircraft operating in that airspace to provide correlation of the weather that was actually encountered with the weather as seen by the radars, so we think this is a very, very important test bed.

Now it was mentioned earlier that we are continuing our studies in the Denver-Stapleton Airport area. We have a 45-day test period underway where we are providing advisories to the tower and, through the tower personnel, to aircraft whenever a microburst is detected by one of the National Science Foundation radars. We have the cooperation of several airlines. United, Frontier, and Continental have agreed to provide feedback to us on their reaction to the type of advisories that are being given.

And, as you have heard from several of the speakers today, one of our concerns is to be able to provide these warnings to the pilot to accurately identify the fact that a microburst does exist, provide its location and intensity, but in so doing not to totally overload the controller in passing out this information. So part of our activity at Denver is to determine the best way to provide these advisories and to measure the reaction of the pilot to the type of advisory that we are giving.

Another activity which we have very much intensified since the data from the JAWS Program has become available from the data analysis activities, is to see to it that this information gets immediately to the pilots and to the airline training people and, of course, to the aircraft manufacturers, so a joint Government-industry team has been set up to review the information that is coming out of the JAWS Program and to jointly develop wind shear models which can be used for simulation training. There have already been two Government-industry workshops, and this process will continue with additional workshops planned.

We have also revised the training film entitled "Probable Cause" to incorporate much of what was learned from the JAWS Program, and we have put out several hundred copies of that film to all of the airlines, not only in this country but through the ICAO organi-

zation to airlines in other countries. We are planning to examine our advisory circulars that deal with wind shear and to update them as appropriate to include things that we are learning out of the JAWS Program, and we are also——

Mr. CARNEY. At that point, Mr. Blake, do you have any timeframe when that might be done?

Mr. BLAKE. We are currently getting the data analyzed and taken out of the JAWS Program, and that is a continuing activity for the rest of this year. We are also, as I mentioned, working with the industry committee as a joint interchange of information, and this activity I think will also run for the remainder of the year.

There is a third related activity, and that is an Air Transport Association wind shear task force which is also looking at the same type of information.

So our review of the advisory circulars is going on in parallel with those activities, and I think we should be in a position to make recommendations this coming year. So it is a continuing process to look at our advisory circulars and update them as appropriate.

In another area, it was mentioned that airborne systems would be most helpful to the pilot. We have, perhaps, designs for part of an airborne system, that part that tells the pilot when he is already in a shear condition and offers guidance on the best way to get the most performance out of the aircraft after having encountered the shear. I think you may be hearing some testimony on that from a following speaker.

The part that is much more difficult and was touched on by our last speaker is to look ahead of the airplane some 30, perhaps 50 seconds, to see if one can reliably detect microburst conditions and to be able to separate out the microburst condition from other less hazardous ones, such as the gust front passage which was demonstrated on the past slides. We have asked NASA to look into a number of things. One is airborne doppler radar systems, and we are jointly funding that investigation. They are funding the infrared investigation that was just summarized for you, and we will continue to look at any other promising technologies in this area.

One area that was brought up by an earlier speaker was the concept of issuing go/no go decision criteria, and I would like to just address that one very briefly. Our systems at the current time are not able—the low-level wind shear alerting system that we have at the current time is not able to positively identify the microburst phenomenon. It does what we designed it to do, and that is to warn the controller when there is a shear existing between the center of the runway and the approach or departure end of the runway. The system was originally developed to do gust front detection, which was perceived as the true threat perhaps in the early 1970 time period. With our increased knowledge base that we have gotten from JAWS, we realize that is not the primary threat, so we have been looking at modification of the existing system to see if detection of the microburst phenomenon is feasible on a fairly reliable basis.

Now we believe that if we are to give criteria to anyone, it should be the pilot, but we also believe that we must develop and implement the type of system which can positively identify the

phenomenon, and we have the two candidates, the possibility of an enhanced low level wind shear alert system and the terminal doppler weather radar system, and we are pursuing both of those activities.

Now another thought that was expressed is the use of wind velocity thresholds and, again, we feel it is better to detect and positively identify the phenomena and warn the pilot of their presence, and then teach avoidance and also, of course, procedures for recovery should you stumble into one accidentally. We do not believe that there is a good threshold wind which would reliably warn of the presence of the microburst.

Looking at the data that we have taken from the JAWS Program, we have seen that the wind increases very rapidly over a very short period of time, reaching peaks characteristically in the 50 to 80 knot vicinity, and then decreases fairly rapidly. The whole phenomenon may be over in 3 to 5 minutes, the longest I have seen from the data in the order of 7 minutes, so it is a very fast-developing and dissipating phenomenon. So we're looking for systems that can give us a little advanced warning that it's forming, that it will shortly be on the ground, so we can tell the pilots.

The National Academy study provided a forum for some of the very, very knowledgeable people on the subject of wind shear to get together and exchange ideas. I believe that our present wind shear programs are generally responsive to the recommendations. Where we believe we had a solution, we are proceeding with the development of the equipment. Where we don't have the answer yet, we have enlisted the help of NASA to do the research activities needed to support future improvements, and we have talked of some of them—the infrared detection, the airborne doppler weather radar. Another one would be the impact of heavy rain on aircraft performance. Now all of these things are ongoing programs under our general wind shear program.

Pilot education is an area that we have stressed and we are continuing to stress and we think, through mechanisms such as a joint industry-Government group, that we can continue to focus the attention of our customers—the airline operators, the pilots—on the question of wind shear and gradually get an increased awareness within the pilot community of the severity and the danger that the microburst does offer.

I think we are encouraged by the fact that we are seeing pilots much more frequently holding when there are thunderstorms in the area, both on the ground and in the air, and pilots declining to take off when they have been informed that such phenomena may exist. We have also seen an increase in the pilot's ability to deal with inadvertent encounters and microbursts. We had an event in 1979, Eastern Air Line at Atlanta. The pilot had been trained in the procedures and did follow them and did save an airplane which almost certainly would have been lost otherwise. We have had the one at Chicago not too long ago, the one at Denver that was discussed earlier, which shows us that proper training in procedures can go a long way toward improving our ability to fly out of these once they are encountered inadvertently.

Mr. CARNEY. Mr. Blake, if I may interrupt you at this point, we have two bells for a vote and my colleague from Tennessee, Mr.

Gore, has some questions he would like to ask of you, and I know his schedule will not allow him to come back after the vote. So if perhaps we could interrupt your testimony, then Mr. Gore could ask the questions.

Mr. BLAKE. Yes. I had essentially covered what I wanted to.

Mr. GORE. Or, Mr. Chairman, if you want to take another minute to finish it up, that would be good too, and we could get them in before the second bells.

Mr. CARNEY. Fine, fine.

Mr. BLAKE. In summary, I think that the FAA Wind Shear Program being conducted in concert with many other agencies—and this is NASA, National Science Foundation, National Weather Service, National Center for Atmospheric Research, the Environmental Research Laboratory, Wave Propagation Laboratory, National Severe Storms Laboratory, Air Force Geophysical Laboratory, the University of Chicago, the University of North Dakota, South Dakota School of Mines, Lincoln Laboratories, and others—is, I think, adequately addressing the recommendation of the National Academy of Sciences and will result in successive improvements in our understanding of the physics of microbursts, our ability to forecast and detect these phenomena, and also our ability to provide improved information on the location and the degree of hazard of the microbursts which will allow us, in turn, to give more accurate warning to the pilots.

[The prepared statement of Mr. Blake follows:]

STATEMENT OF NEAL A. BLAKE, DEPUTY ASSOCIATE ADMINISTRATOR FOR ENGINEERING, FEDERAL AVIATION ADMINISTRATION, BEFORE THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY, SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS CONCERNING WIND SHEAR DETECTION TECHNOLOGIES, JULY 25, 1984

Thank you, Mr. Chairman. I am privileged to come before this Subcommittee today to discuss the Federal Aviation Administration wind shear program, and to specifically address wind shear detection technology. With me, are Mr. Kenneth S. Hunt, Director, Office of Flight Operations, and Mr. Willard Reazin, Manager, Procedures Division of the Air Traffic Service.

To begin I would like to briefly discuss the wind shear phenomena, give you a little background on prior FAA wind sheat activities, and then address our current program and some specific systems, such as the Low Level Wind Shear Alert System (LLWAS), the Next Generation Weather Radar (NEXRAD), and its possible terminal derivative, and then discuss FAA plans for implementing the recommendations of the National Academy of Sciences' Low-Altitude Wind Shear Study.

The wind shear problem is certainly not new to the aviation community; the FAA has carried on an extensive program in this area since the early 1970's. Wind shear occurs throughout all strata of the atmosphere, but it is low altitude wind shear or wind variability that causes the greatest safety concerns. Wind shear becomes an extremely critical factor in aircraft operations in the airport environment when the aircraft is in the most susceptible mode: low altitude, low speed, and aerodynamically "dirty" or in a high drag configuration. Early in wind shear investigations and research it was thought that the approach and landing phase was the most crucial operation, because the majority of wind shear related accidents occurred during landing. However, a series of recent accidents and incidents have shown that wind shear can have dramatic effects on takeoff performance. The Joint Airport Weather Study conducted by the National Center for Atmospheric Research (NCAR) and the University of Chicago and co-sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration (NASA), and the FAA, has convincingly demonstrated that certain types of wind shear can exceed the performance capability of the most modern airplanes.

Wind shear is caused by several atmospheric mechanisms: frontal movement (both cold and warm), sea breeze effects, gravity waves, the low level jet stream effect (predominately a central plains phenomena), and convective activity or thunderstorms that spawn gust fronts, downbursts, and the recently well documented microburst. Additionally, the National Severe Storms Laboratory in Norman, Oklahoma, has conducted extensive research and analysis the past few years on the "solitary wave" or detached gust front that can preceed convective storms by several hundred miles. Also, there are the orographic or mechanical shears, such as mountain waves, the Santa Ana type winds, and shears induced by large structures, tree lines, and irregular terrain features. Wind shear can take many forms, it can be insidious or abrupt; and an unexpected encounter by a pilot can sometimes be disastrous.

The Federal Aviation Administration conducted an intensive research and development wind shear program from 1975 through 1980. Objectives of this program included: the characterization of wind shear; definition of the hazards; improvement in wind shear forecasting; investigation and testing of wind shear detection techniques and equipments; and research, through piloted simulations, on airborne systems and techniques that could aid the pilot in coping with wind shear encounters. An early result from this program was the incorporation in 1978 of frontal wind shear forecasts into area and terminal forecasts by the National Weather Service (NWS). And more recently Dr. Theodore Fujita of the University of Chicago, as a part of the Joint Airport Weather Study, developed techniques for identifying the atmospheric mechanisms that are used to forecast microburst occurrence. A major part of our early wind shear program was the evaluation of wind shear detection technology. We devoted considerable resources to the development, testing, and evaluation of ground-based wind shear sensors.

Ground-Based Wind Shear Sensors:

The simplest and most straightforward sensor is the anemometer. Obviously it can only measure wind speed and direction "in situ" and cannot be used for sensing of wind at higher levels. Its advantages are reliability, maintainability, and its data are easily processed by computers.

Microbarographs or pressure jump detectors were tested at three locations: Dulles, Chicago, and Atlanta. Tests on pressure sensors were inconclusive, and though effective in detecting some shear conditions, their use cannot guarantee recognition of all atmospheric conditions that cause hazardous wind shear. The systems tested were subject to excessive false alarms, and adequate coverage for an airport requires a high density network of sensors.

Acoustic radar or Sodar is another technology that was examined. The acoustic radar can measure winds above the surface to a height of approximately 500 meters, but it is limited in sensing volume and has no scanning capability. A serious disadvantage of acoustic devices is that they are strongly affected by noise from heavy rain, high surface winds, and aircraft engines. Providing full coverage for a large airport in all likelihood would require at least one or more sensors in every approach corridor, an airport like Chicago's O'Hare might require up to 12 sensors.

Lidars, both frequency modulated continuous wave and pulsed, are very effective wind measurement sensors. The FAA has employed a low power, FM-CW laser Doppler velocimeter as both a wind shear and wake vortex detector. Lasers suffer substantial attenuation in fog, rain, and snow. Their main advantage is the capability to operate in clear air and achieve accurate measurements from the backscatter from small particulates normally found in the atmosphere. FM/CW lasers are effective to approximately 2,500 feet and NOAA's Wave Propagation Laboratory has measured winds in clear air at a range of 18 kilometers with an experimental pulsed laser Doppler velocimeter. Lasers provide good volume coverage and have scanning capability. Their major disadvantages are signal attenuation in bad weather, cost, and the high computational capability required for near real-time operation. The Royal

Aircraft Establishment, Bedford, U.K., has developed and flight tested an airborne lidar. The system was developed as a true airspeed sensor, but has demonstrated the ability to provide approximately 4 seconds of warning time to the pilot in significant shear situations. This system was flown in an HS-125 during the Joint Airport Weather Study. Should it prove possible to extend the range and warning time of the airborne lidars this may be a viable and effective airborne answer to the wind shear problem. FAA is working with NASA to develop a research program on airborne sensors for low altitude wind shear detection.

Infrared Radiometry has been proposed as a candidate wind shear detection system. IR Radiometers measure temperature differential in the atmosphere. Experimental ground and airborne systems have been developed and tested. During the Joint Airport Weather Study Program an airborne system was utilized in some of the experiments. Based on the analysis of the JAWS data, temperature differences are not reliable indicators of microburst occurrences. No definitive temperature change could be established in the microburst data; the change could be plus or minus and the range was generally from 1 to 3 degrees. Additionally, infrared devices, like lasers, suffer substantial attenuation in rain and snow.

Doppler weather radar is the last major sensor that we have investigated. I will be discussing our program in this area later in the presentation.

In parallel with this activity our flight operations and training people conducted pilot education and awareness programs, such as the General Aviation Safety Seminars and issuance of operations bulletins to our principal operations inspectors. In 1976, Advisory Circular 00-50 "Low Level Wind Shear" was published and then updated in 1979. The information and guidance contained on this advisory circular is sound and has proven operationally effective. We are currently working with the Air Transport Association Wind Shear Task Force on a revision to AC 00-50A "Low-Level Wind Shear" to incorporate recent meteorological findings and refinements to pilot procedures.

Wind shear profiles developed in the FAA, Douglas Aircraft Company, and Stanford Research International (SRI) simulation program were made available to airline training groups and the industry and airlines were encouraged to develop wind shear training programs. There have been several instances where wind shear training conducted by airline companies enabled pilots to escape severe wind shear encounters and avoid accidents. Two specific cases come to mind; in one case an Eastern flight crew on approach into Atlanta in August 1979 used the procedures recommended in AC-00-50A and taught by their company, abandoned their approach and successfully negotiated a severe wind shear encounter, then landed safely. In the other instance, a United flight crew encountered a strong wind shear and heavy rain right at the rotation point during a takeoff at O'Hare, and using the techniques taught in the United training program they maintained control of the aircraft and were able to safely continue.

The FAA has always recognized that avoidance, whenever possible, should be the primary method for dealing with wind shear, but we also recognize that inadvertent encounters can and will occur, so we are continuing to work on improved systems to attack the problem. We will continue to provide the latest information on wind shear to the aviation community as it becomes available.

With this background to set the stage for our discussions I would like to now address the specifics of our current programs and activities.

One of the key results of our earlier programs was the development and deployment of the Low Level Wind Shear Alert System (LLWAS) at 59 airports. We are in the process of equipping an additional 51 airports. This activity will be completed by the end of next year and will provide alerting service at a total of 110 airports. The LLWAS was developed primarily to warn of wind shears caused by fast moving fronts and thunderstorm gust fronts, and is a surface wind measurement system that cannot remotely sense wind shears at approach altitudes. The system's primary component is a set of mechanical anemometers supported by computer-based data processing and display components. Five remote anemometers are strategically located around the periphery of the airport and their wind data are compared to a single centerfield anemometer. A 15-knot vector difference between the centerfield and any remote site triggers an alert in the control tower and the controller passes advisories to traffic in the airport area. Because this system was developed before the "microburst phenomena" was fully understood, the spacing of the sensors will not effectively detect that type of wind shear. To test the capability of the LLWAS to detect microbursts we have augmented the system at Moisant Airport in New Orleans. Five additional sensors have been added to the anemometer network and the processing algorithms and software have been changed. The test bed system is now installed and operational. We will continue to test and evaluate the modified system over the next year. The results of this test will provide the basis for decisions on modifying the LLWAS. In conjunction with the New Orleans tests, the National Center for Atmospheric Research is conducting further computer simulations and analyses on alternative algorithms and display techniques. We are optimistic that the modifications incorporated in the Moisant system will provide more effective airport coverage, reduce the number of false alerts, and possibly confirm the capability to detect microbursts. Additionally, we are planning to record and archive the data from the system and these data will be analyzed to provide improved siting criteria and increase the climatological data base on wind shear.

Another system which is being implemented this year is the Radar Remote Weather Display System (RRWDS). I hasten to add, however, that this is not a wind shear detection system, per se. Certainly knowledge of the location and movement of severe weather and thunderstorms will serve as a warning of possible wind shears and turbulence. The RRWDS was developed to provide current weather information from National Weather Service radars and FAA long range radars (Air Route Surveillance Radars) to the Center Weather Service Units, FSS En Route Flight Advisory Service locations, and NWS Weather Service

Field Offices. The data are also available to the weather service unit in the Central Flow Control Facility in FAA headquarters. Radar digitizers have been installed in 77 NWS radar sites and 57 FAA radar sites. RRWDS displays are located at 20 air route traffic control centers, the Central Flow Control Facility, 44 en route flight advisory service locations, 2 high activity flight service stations, and 10 weather service field offices. We have procured and installed a total of 134 transmitter site digitizers and 151 displays at 77 locations. The meteorologists at the Center Weather Service Units and the weather service field offices are presently utilizing the radar data in their daily operations. The En Route Flight Advisory Service and FSS locations have fully operating systems, but we have not completed training of our FSS specialists. All RRWDS locations should be fully operational by the end of this year.

The Next Generation Weather Radar or NEXRAD program is an ongoing triagency development of a replacement weather radar that will serve the needs of the National Weather Service, the military, and the Federal Aviation Administration, as well as other Government agencies and the nation. NEXRAD will replace the existing network of weather radars and, for aviation purposes, is expected to provide information on hazardous weather for the nation's en route airspace. Conventional radar measures only reflectivity, i.e., intensity of the return signal. Doppler weather radars have the added ability to measure the radial velocities of particles in the atmosphere. A Doppler radar can, therefore, measure radial wind velocity, a key element in the detection and measurement of severe weather.

A network of radars is planned that will provide weather radar coverage above 10,000 feet throughout the entire country, and possibly provide coverage down to 6,000 feet in nonmountainous terrain. Aviation weather products to be provided by the NEXRAD include: winds, turbulence, thunderstorm detection, storm movement prediction, precipitation intensity, hail detection, frontal movement, freezing levels, mesocyclones/tornadoes, and hurricane intensity and movement.

The NEXRAD validation phase contracts were awarded last year to Raytheon and Sperry for the production of prototype radars; this phase of the program is scheduled for completion in December 1985. Production units are to be installed from 1988 through 1992.

The FAA is a full time participant in this program and is preparing to utilize the NEXRAD weather information throughout the National Airspace System. We have ongoing development programs in weather processors to provide NEXRAD products to the Advanced Automation System for controller use and, through data link services, to the pilot.

NEXRAD, however, will not solve the low altitude wind shear problem in the terminal area. Use of Doppler weather radars for wind shear detection is feasible, and early work by the National Severe Storms Laboratory in the application of single and multiple Doppler radars confirmed the capability to

detect and measure the intensity, radial velocities, and spectral width (turbulence) in thunderstorms. The experiments conducted by the Northern Illinois Meteorological Research on Downbursts (NIMROD) provided the basis for Dr. Theodore Fujita's early identification and characterization of the microburst. The results from this Doppler radar research that the FAA and other agencies have sponsored over the last 15-20 years, as well as the continuing analysis of the Joint Airport Weather Study data, reinforce the concept of a terminal Doppler weather radar as a wind shear detection system.

The FAA is actively examining the technical and funding implications of initiating a Terminal Doppler Weather Radar program. The FAA has studied a number of alternatives including: development of a "C" band weather radar, addition of a Doppler weather channel to the ASR-9 terminal ATC radar, modification of commercial Doppler weather radars, and a NEXRAD derivative "tuned" for wind shear detection.

We have a development program for a Terminal Doppler Weather Radar underway. Planning for a terminal weather radar test site at Memphis International Aiport was completed last fall. Lincoln Laboratory has assembled a transportable terminal Doppler test bed radar and has developed processor algorithms tailored for use in the terminal environment. This system, in conjunction with a second Doppler radar operated by the University of North Dakota, will be used to assess radar performance at both on-airport and off-airport locations and to evaluate scanning strategies, data processing, and data display techniques.

The transportable test bed is presently being installed at the Olive Branch, Mississippi Airport which is approximately ten miles southeast of Memphis International Airport. The University of North Dakota "C" Band Enterprise radar is located six miles south of the Memphis Airport. We will also acquire supporting test data from the NWS WSR-57 radar near Memphis, the Low Level Wind Shear Alert System, and an additional thirty unit Mesonet array providing winds, temperature, and pressure measurements. Two flight test aircraft from the FAA Technical Center and the University of North Dakota will participate in the research. The Memphis tests are planned to run for a full year, and will be used to resolve technical issues associated with the operational use of Doppler weather radar in the airport environment.

I would like to mention at this point that the FAA has recently implemented an operational evaluation of microburst forecasts, and detection and warning techniques in the Denver-Stapleton area. We have contracted with the National Center for Atmospheric Research (NCAR) to provide microburst forecasts on a daily basis and provide Doppler radar surveillance and real-time advisories of microburst activity to the control tower. This activity was started on July 7 and will continue through August 15. Radar coverage is provided from 1100 to 2000 hours, Mountain Daylight Time, 7 days a week. The daily forecast is issued at 1000 local time and is transmitted through the Denver Center on the Service A network. United, Frontier, and Continental Airlines have agreed to provide more detailed feedback from their pilots on the efficacy of the advisories. We have already seen several days when there has been significant

microburst activity in the vicinity of Stapleton. A thorough analysis of the results of this evaluation will be accomplished when the project is completed. This is the first step in the process of determining how the information supplied by a Doppler radar can be applied to terminal operations.

My comments on radar thus far have largely been confined to ground-based systems, but we are working closely with the National Aeronautics and Space Administration to establish a research effort on the possible applications of airborne Doppler weather radars for wind shear detection and avoidance. NASA has already successfully demonstrated the capability of an airborne Doppler radar to measure wind shear in the absence of ground clutter. This radar was a brassboard, rearward-looking research device that viewed storms at altitude in areas free of ground clutter. A major technical problem that must be addressed is the suppression of ground-clutter returns when the radar is operated in the forward looking mode during approach and landing. There are commercial airborne Doppler weather radars available today, but they basically detect turbulence in precipitation and, to our knowledge, do not measure wind shear--particularly in clear air or dry microbursts.

NASA, as a part of their research, will try to develop improvements for current state-of-the-art airborne radars, to evaluate their capability to detect wind shear. We will continue to support NASA research on airborne wind shear detection systems because we feel strongly that avoidance is key in severe wind shear situations, and an airborne detection system will provide protection in all flight regimes and locales.

Mr. Chairman, I have reviewed most of our major wind shear activities, but the wind shear problem has many facets and there are a few other activities that I should mention before moving into the National Academy of Sciences' study and our plans for implementing their recommendations.

I have mentioned the Joint Airport Weather Study and there are one or two activities closely related to the JAWS program that deserve comment. Drs. McCarthy and Fujita and their teams are continuing to reduce and analyze the wealth of data available from JAWS. The completed analysis of the meteorological data from the study will be used to develop improved wind shear models for simulation programs for training, as well as avionics design and certification. There is a joint NCAR/NASA/FAA/industry committee that has steered the work to develop wind shear models for simulation. It has already held two Government/industry workshops and will continue to provide advice and input on the model development effort and their applications.

NCAR and the JAWS team are also working with our Low Level Wind Shear Alert System program manager in developing improved siting criteria and refined operational algorithms to enhance the LLWAS performance. They are optimistic that redesign of the present system can provide capability to identify microburst occurrences on the airport using the surface detection system.

The JAWS team also collaborated with our Office of Flight Operations in the production of a new videotape on wind shear and the microburst phenomena for

pilots, controllers, and meteorologists. Over two hundred copies of this audiovisual training film, entitled "Probable Cause," have been distributed to every major air carrier and the general aviation community. It was also made available to ICAO for reproduction and distribution to non-U.S. carriers. The film stresses the importance of avoidance whenever possible, and describes recommended flight control techniques, and the environmental clues associated with wind shear conditions, particularly microbursts.

As I previously mentioned, we are planning to update Advisory Circular 00-50A with current meteorological information and additional guidance on control techniques. We are working with an Air Transport Association Wind Shear Task Force on this revision.

In November 1983, the Office of Flight Operations released Advisory Circular 120-41 "Criteria for Operational Approval of Airborne Wind Shear Detection Equipment." This circular describes an acceptable methodology for evaluating airborne wind shear equipment. We are already planning to revise that circular with improved wind shear models based on JAWS data and the work of the joint Government/industry committee on wind shear modeling.

There is another specific area that requires further study. Following the Pan American Flight 759 accident at New Orleans, the National Transportation Safety Board issued the following recommendation (No. A-83-18): "Evaluate methods and procedures for the use of current weather information from sources such as radar, Low Level Wind Shear Alert Systems, and pilot reports as criteria for delaying approach and departure operations which would expose the flight to low altitude penetration of severe convective weather."

We do not necessarily disagree with the concept upon which this recommendation is based. Some form of pilot go/no-go decision criteria during periods of severe weather would be highly desirable. Given the status and capabilities of the current systems we believe that the promulgation of such criteria may be premature. To successfully implement criteria, as suggested, requires that we be able to accurately identify the phenomena, particularly in the downburst/microburst case. Presently, we are working on two systems which could possibly achieve the needed reliability and accuracy, the enhanced LLWAS and the terminal Doppler weather radar. Wind velocity thresholds have been proposed as a possible criterion, but generally wind shear velocities go through a threshold rapidly and intensify over a very short period of time. This is especially true of thunderstorm generated wind shear conditions. We feel it is more important to recognize the downburst/microburst phenomena and issue advisories on that basis. It appears vital that recognition occur at the formation stage so the advisory is timely, with minimum false or unnecessary advisories. The FAA will continue to work on this problem to provide the best possible guidance to pilots and contollers during periods of severe weather.

Mr. Chairman, I believe that completes my comments on the history and highlights of the FAA wind shear program. As you have requested, I will now move on to the National Academy of Sciences' recommendations and our plans for

implementing them. I think it is also appropriate to note here that the National Academy study contains an excellent review of wind shear detection technologies in Chapter 2, "Low Altitude Wind Shear."

The National Academy study published last November made 19 recommendations, grouped into four categories: General, Detection and Prediction, Aircraft Performance and Operations, and Research. In general, the FAA accepts the recommendations of the study group and we believe that our present wind shear programs are responsive to most of their recommendations.

1. Need for An Integrated Wind-Shear Program.

"To provide for the safety of the flying public, the FAA and the aviation industry should address the many facets of the low-altitude wind shear problem as a whole. The FAA should develop and implement a coherent and sustained program for coping with the educational, meteorological, technological, and operational aspects of low-altitude wind shear hazards."

The Weather Coordination Program Staff has been designated to serve as the focal point for our wind shear activities and a staff member, Mr Myron Clark, has been named as the Wind Shear Program Coordinator. Mr. Clark will develop an integrated wind shear program plan that will serve to coordinate the activities of the various wind shear related programs in the FAA and elsewhere. Through the program plan we can ensure that the FAA follows a sustained and coherent plan in addressing the wind shear problem.

2. Wind Shear Education Program.

"The FAA and the industry should prepare and disseminate as widely as possible updated and authoritative information on wind shear. Informational materials should stress avoidance of wind shear and should describe flight control techniques for recovery from encounters. The information should encompass all types of aircraft, with appropriate guidance for each class. It should include recommendations on the most effective means of training pilots.

The FAA should revise and update its 1979 Advisory Circular (AC 00-50A) on wind shear and the Airman's Information Manual (AIM) to present the latest information, including detection techniques, alerting and warning procedures, effects of wind shear on aircraft performance, and procedures for recovery from wind shear encounters."

As I indicated earlier, the FAA is concerned about pilot awareness and understanding of the wind shear phenomena and appropriate pilot actions during an inadvertant encounter. The Office of Flight Operations considers pilot education, as well as pilot training on wind shear, a priority task. We will continue to make an effort to reach out to the aviation community through our normal channels of communications, such as: Notices to Airmen, Letters to Airmen issued by both the Air Traffic Service and the Office of Flight Operations, Safety Bulletins, Operations Bulletins to commercial operators, the General Aviation Accident Prevention Program, which has full time safety

specialists assigned to the program, Biennial Flight Reviews (to which we are considering adding a weather training segment), and the Airman's Information Manual (AIM). In regard to the AIM, a task group of the National Airspace Review has just completed a staff study and has developed recommendations for reconfiguration and simplification of that publication. Also, the Air Traffic Service is presently coordinating a contracted study on how the FAA can improve the availability, readability, and salability of the AIM.

We support and cooperate with public communications media by providing current information on aviation issues.

The Office of Public Affairs is in the process of producing an audiovisual on aviation weather in general, and Flight Operations is planning to update "Probable Cause", our wind shear training film.

Air Carrier Principal Inspectors will continue to stress the importance of wind shear awareness in recurrency training and flight reviews. The Office of Flight Operations' General Aviation Division has an active pilot safety seminar program and will continue to make current information on wind shear available to the general aviation community. It will continue to work closely with the various general aviation associations, such as the Aircraft Owners and Pilots Association and the General Aviation Manufacturers Association, to provide the latest published information on wind shear.

The FAA recognizes this as a problem area and we are working on it.

3. Pilot/Controller Communications.

"The FAA should promote the use of standardized terminology and improved communications between flight crews and control towers. A standardized system of pilot reports (PIREP's) should be developed for reporting low-altitude wind shear encounters. PIREP's should be mandatory and should include a report of the location, severity, and nature of the shear encountered--in consistent, standardized terminology. Controllers should communicate such reports to all flight crews in the vicinity. In addition, techniques for the direct broadcast to pilots of wind shear data from LLWAS or other sensors should be investigated."

The acquisition, dissemination, and standardization of format and terminology of PIREP's have been, and continue to be, an important part of the development of an effective Aviation Weather System. There is an ongoing effort, in concert with the National Weather Service (NWS) and concerned pilot organizations, to improve PIREP procedures. The FAA has provided further guidance to controllers on the solicitation and retransmission of pilot weather reports, including wind shear report, and the procedures for wind shear advisories at Low Level Wind Shear Alert System (LLWAS) equipped airports, in the latest revisions to FAA Handbook 7110.65C, "Air Traffic Control," and FAA Orders 7110.84, "Terminal Area Pilot Weather Reports (PIREP's)," and 7210.3-1222, "Low Level Wind Shear Alert System (LLWAS)."

Mandatory pilot reporting of wind shear encounters appears, on the surface, to be an excellent way to force an improvement in this area. However, "mandatory" implies regulatory action and, by definition, must be enforceable. It is evident from the National Academy of Sciences' report that we are not currently in a position to determine independently whether or not pilots are reporting all wind shear encounters. The FAA will continue to encourage pilots to report wind shear encounters expeditiously.

Direct broadcast to pilots of wind shear data from LLWAS or other sensors is planned when MODE-S is available. However, the FAA will investigate the technical and operational feasibility of the direct broadcast of such data via an interim system provided no human interpretation of sensor data is needed.

4. Wind Shear Detection System Development.

"The FAA should select a site to test direct and remote-sensing techniques in a complete system for detecting low-altitude wind shear and for providing information to pilots and controllers and to test the use of the information in the air traffic control system. The test site should be at a major airport where wind shear conditions are relatively frequent."

The FAA feels this recommendation has been acted on with our establishment of the Memphis and New Orleans test sites.

Recommendations 5 and 6 in the study dealt with the Low Level Wind Shear Alert System improvement and recording of LLWAS data. Since we have already described our activities that address these recommendations, I will not repeat that discussion here.

7. Use of Available Radar Data.

"The existing network of weather radars, operated by the NWS, should be used more effectively to judge the likelihood of wind shear conditions. These radars detect rain showers, thunderstorms, and phenomena often associated with wind shear. Information from weather radars should be made available to air traffic controllers in a timely and easily understandable fashion."

In developing this recommendation, the committee was addressing the fact that many major airports are within the coverage area of a National Weather Service weather radar, and that controllers in the towers at these airports should have access to a display of the information from these radars. If such information were available to the tower controllers, they could then better advise pilots of the weather situation in the immediate airport area. The committee felt that the FAA was not taking advantage of useful information that exists and would be relatively inexpensive to provide.

The FAA will determine the feasibility of providing existing NWS radar weather information to control tower cabs so that controllers can provide the latest severe weather warnings to pilots prior to departure or landing. This would require the installation of a weather radar display in an operating tower cab,

and we believe some processing of the information would be required to allow rapid interpretation of the meteorological phenomena. It should be pointed out, however, that existing FAA terminal radars already provide some indication of severe weather and, depending upon the relative location of the NWS radar, may provide better severe weather information than the NWS radar; also, the new ASR-9 will have a weather channel.

Recommendations 8 through 11 dealt with accelerating NEXRAD development, developing an Airport Terminal Weather Radar, and Airborne Sensors. These programs have been discussed previously.

Recommendations 12 and 14, which must be considered together, are the most difficult to respond to because they are so all encompassing and the work that has been accomplished in this area was very comprehensive.

12. Wind Shear Effects on Flight Characteristics.

"The FAA should sponsor analytical and simulator investigations to determine:

- The wind shear penetration and recovery capabilities of transport aircraft, based on various onboard detection, guidance, and control systems.

- The effects of wind shear on various typical categories of general aviation aircraft and helicopters so that authoritative information on their response characteristics and piloting techniques in wind shear can be provided."

The FAA believes that the first step in assessing the effects of wind shear on aircraft performance requires an accurate determination of wind shear profiles or models. Once we have established an acceptable set of models, a comprehensive evaluation should be accomplished through simulation, both fast-time and piloted. As I mentioned before, we are cooperating with the National Center for Atmospheric Research, NASA, and industry in the development of models; and in conjunction with the model development, the group will propose guidelines for their implementation and application.

For training and equipment design and certification the models are critically needed, but the more practical approach is the early development of better forecasting techniques (particularly for thunderstorm, downburst, and microburst forecasts) and the development and deployment of detection and avoidance systems.

We think that our current Advisory Circular on Low Level Wind Shear and the planned update that a joint FAA/industry working group is developing still identifies the best technique for maximizing aircraft performance in wind shear. I have already cited examples where properly applied piloting techniques have been successful. We will continue to work with the aviation industry to perfect our knowledge in this area.

The FAA, in conjunction with NASA, Douglas, Boeing, and SRI International, carried out extensive simulation studies that addressed airborne displays, instrumentation, and procedures for aiding pilots in coping with unexpected wind shear during approach and takeoff. This was a thorough, 4-year effort involving a wide spectrum of guidance and control aids for transport category aircraft. There have been no significant breakthroughs in either basic aerodynamic design or onboard guidance and control systems since these studies were completed in 1979. Because of this, the FAA will be working very closely with NASA and various user groups to define more precisely the work that needs to be accomplished in this area. One user group, the Air Transport Association, has already formed a Wind Shear Task Force to address issues such as this. Our major concern in this area is that the extensive and rigorous experimentation recommended would requife significant resources and would result in only a very limited, if any, increase in the wind shear knowledge data base. This, by itself, is significant, but becomes much more significant when coupled with the fact that there can still be instances of severe wind shear encounters that would not be survivable. This is the reason that the FAA stresses avoidance as the optimum method for dealing with wind shear and would prefer to see resources invested in the development of an operationally acceptable airborne detection system. Such a system would provide wind shear avoidance capability in all aircraft operating environments and in all locations worldwide.

14. Guidance and Control Aids.

"Onboard sensors and guidance aids should be evaluated in a systematic manner to determine their merits for future development and for possible retrofit in existing aircraft. These include flight director modifications, ground speed/airspeed flight mnagement systems, vertical-acceleration sensors, and energy-rate sensors. Angle-of-attack indicators should be added to the cockpit instrumentation of transport aircraft for use in maneuvering through wind shears. Angle of attack should be provided either as a separate variable or as an input to other command displays. Sensors should provide flight crews with a voice warning of a hazardous wind shear."

The evaluation of onboard sensors and guidance aids (Recommendation 14) is an integral part of Recommendation 12, and the discussion of that recommendation for the most part applies here as well. Regarding the recommendation that angle-of-attack indicators be added to the instrumentation of transport aircraft or be provided as an input to other command displays, it should be pointed out that angle-of-attack information is utilized in our present generation of transport aircraft. Angle-of-attack indicators are not standard instrumentation, but the inputs from angle-of-attack systems are used by a number of flight directors, flight management systems, stall warning systems (stick shaker), and wind shear detection and guidance systems. The FAA will continue working with the Air Transport Association Wind Shear Task Force, NASA, and other advisory groups to address the issue of angle of attack and its application to the wind shear problem.

13. Aircraft Operating Procedures.

"The FAA should ensure that air carriers and other commercial operators instruct flight crews on what to do if they inadvertently encounter a low-altitude wind shear during takeoff or landing. In addition, the FAA should encourage operators of jet aircraft to incorporate in their manuals the operating procedures recommended in its advisory circular on wind shear. Aircraft manufacturers should recommend configuration-change sequences (gear, flaps, power, spoilers, etc.) that provide the highest probability for recovery from a wind shear encounter. Pilots should be taught to exceed the normal maximum thrust limits and to go to emergency thrust when necessary."

The Office of Flight Operations has issued air carrier operations bulletins that provide guidance to all carriers and commercial operators with reference to crew training and operating procedures for wind shear encounters.

The required FAA approved airplane flight manual (AFM), which accompanies all certificated aircraft, is not suited for presentation of wind shear procedures. The FAA specifically avoids inclusion of information relating to airmanship in the required AFM. Individual commercial air carriers are empowered to publish their own crew operating procedures manuals (i.e. airplane operations manual (AOM)) that incorporate all FAA required flight manual information, plus other information appropriate to their individual operations. These operations manuals often provide information related to airmanship, and carriers are encouraged to include best known wind shear procedures. For other operators of turbine powered aircraft who use only the FAA approved AFM, the FAA Accident Prevention Program currently disseminates information concerning wind shear in pamphlets, films, and discussions at pilot forums. Accident Prevention Specialists discuss the phenomena and best known techniques and procedures at well attended seminars.

General aviation operators are encouraged to become familiar with wind shear advisory material such as AC 00-50A. Instructors are encouraged to observe during biennial reviews proficiency and knowledge concerning wind shear. The FAA believes this program provides the best means for disseminating information relating to airmanship.

15. Standardization of Wind Shear Models.

"The FAA should sponsor a program to develop and define standardized models of wind shear based on the latest meteorological data. These models are required for design and certification of aircraft subsystems and for use in training simulators. The FAA should include other Government agencies, aircraft manufacturers, commercial operators, and any other interested parties in the program."

This recommendation is being acted on. As I mentioned earlier, we are continuing to support the reduction and analysis of the JAWS data base to develop standardized wind models for training and equipment design and certification.

An additional activity, sponsored by the Office of Flight Operations, is currently in progress to investigate the incorporation of wind shear profiles and associated training techniques into all categories of flight simulators ranging from general aviation to transport types.

16. Certification of Onboard Systems.

"The FAA should update its certification requirements for airborne wind shear alerting, flight guidance, and automatic control systems."

FAA's Office of Flight Operations has recently released Advisory Circular 120-41 "Criteria for Operational Approval of Airborne Wind Shear Detection Equipment" and will update this advisory circular with the latest wind shear data when the final analyses of the JAWS data set are published. The appropriate FAA offices will reexamine current guidance material on the certification of flight guidance and automatic control systems to determine if revisions are required.

17. Wind Shear Simulation Training.

"The FAA and the industry should cooperate to investigate new and innovative ways to make available the best possible simulation training for wind shear to the largest possible number of pilots, including general aviation pilots."

The FAA has taken steps to facilitate improved wind shear training for user groups. FAA, NASA, and the National Center for Atmospheric Research have sponsored workshops with industry to make available the most current wind shear data. The basic objective of these workshops was to give the various user groups the opportunity to review the format, quantity, and quality of the data, and consider possible training applications of the data sets. Since each user has unique requirements for data, based on their individual training objectives and their individual simulation capability, the data must be examined in light of its most cost-effective applications. FAA will continue to make available to the aviation community all information and data resulting from future research and experimentation.

18. Effects of Heavy Rain.

"Investigations should continue on how heavy rain affects the low-speed aerodynamic characteristics of aircraft. Particular attention should be paid to the possible adverse effects of heavy rain on aircraft lift, performance, and controllability, including its effects on wind shear detection and flight sensor systems."

FAA agrees with this recommendation. NASA has an ongoing program to investigate the effects of heavy rain on airfoil efficiency and aircraft performance. Recent NASA experimentation has established that heavy rain appears to reduce lift in a wind/water tunnel environment, but this experimentation needs further refinement and testing. FAA is providing support and guidance to NASA's research and will consider appropriate action when NASA's experiments have been completed.

19. The Nature of Low-Altitude Wind Shear.

"More must be learned about the various kinds of wind shear and the meteorological conditions that cause or are associated with them. This knowledge is needed to reduce the hazards represented by low-altitude wind shear. Research should include additional field observations and the construction of theoretical models over the relevant scales -- from about 1,000 feet to 10-20 miles and from minutes to hours.

The existing body of data obtained by various research programs should be reexamined and augmented, at an appropriate time, by a field program in the humid southeastern United States. Analyses of the data obtained from the JAWS Project should be used to plan any new field investigation. Basic research into the origins of strong thunderstorm downdrafts and possible forecast methods should be an important component of any new program."

FAA will consider the requirements for additional wind shear research after an assessment has been made of the availability of data from planned and ongoing meteorological research activities. In response to Recommendations 5 and 6, additional data from the archiving of LLWAS measurements will be analyzed and incorporated in existing wind measurement data bases. Additionally, radar and surface mesonet data will be acquired and analyzed as part of the Memphis terminal Doppler radar tests. In the longer term, the National Oceanic and Atmospheric Administration has established programs that will provide substantial data sets, both surface and upper air, for analysis and study. The Stormscale Operational and Research Meteorology (STORM) Program, currently being planned by the National Center for Atmospheric Research and supported by the National Science Foundation, NOAA, NASA, FAA, DOD, and university research groups, will contribute to the knowledge of mesoscale convective activity and forecasting techniques to provide near real-time response to small scale severe weather conditions.

This finishes my discussion of the National Academy of Sciences' study, and before concluding my remarks I have one last topic to discuss. Some pilot groups have recommended that accurate knowledge of the horizontal shear that the aircraft will fly through would facilitate safer pilot decisions. We have tasked the FAA Technical Center, as part of the LLWAS enhancements program, to investigate if the system software could be programmed to extract this information from the LLWAS data. Since most wind shears are short-lived and grow rapidly in intensity, the best procedure and the one we recommend is avoidance; but we will continue to explore avenues to provide the pilot with full and accurate information on the airport weather environment. We believe that the FAA wind shear program that is being conducted in concert with other agencies, including NASA, NSF, NWS, NCAR, Environmental Research Laboratory (ERL), Wave Propagation Laboratory (WPL), National Severe Storms Laboratory (NSSL), Air Force Geophysical Laboratory (AFGL), University of Chicago, University of North Dakota, South Dakota School of Mines, Lincoln Laboratory, and others, is addressing the recommendations of the National Academy of Sciences and will provide successive improvements in our understanding of the physics of microbursts, our ability to forecast and detect these phenomena, and also availability to provide improved information to both controllers and pilots on the location and degree of hazard of a microburst. The ability to warn accurately of the presence of wind shear and the development of the phenomena will provide a significant improvement in flight safety.

Mr. CARNEY. Thank you, Mr. Blake.

Mr. Gore.

Mr. GORE. Thank you very much, Mr. Chairman.

Mr. Blake, I am really excited about this project being located in Memphis. Am I correct in saying that if this test proves that the doppler technique is the most successful way to avoid the dangers of wind shear and microburst, then the same equipment now installed at Memphis will one day be installed at airports throughout the United States?

Mr. BLAKE. Well, it is certainly our hope that the type of equipment we will be testing there will provide the pattern for equipments to follow. We are excited about all of the results that have already come out of the doppler program and we are trying to excite others that this is perhaps a good way to go, and we are exploring the technical and economic aspects that would go with an implementation program of this type.

Mr. GORE. Is it fair to say that for the time being, at least, insofar as wind shear is concerned, Memphis is the safest airport around?

Mr. BLAKE. Well, we hope to make it that. [Laughter.]

Mr. GORE. So any airlines looking for a place to locate a new hub ought to take that into consideration. [Laughter.]

Mr. BLAKE. Well, certainly if we can improve the safety with devices of this kind——

Mr. CARNEY. Senator, we're not getting parochial, are we? [Laughter.]

Mr. GORE. I would be glad to yield to the gentleman from the crowded sky area of New York.

No; I wouldn't do that.

Mr. CARNEY. I might add, we never get delays at Long Island McArthur Airport.

Mr. GORE. Yes; we've noticed. We've noticed. No more than 8 hours.

Now your intention at Memphis is to learn how to use these new radar technologies for guidance of aircraft on takeoff and landing, where they are most vulnerable. Is that essentially correct?

Mr. BLAKE. Yes; we have several objectives. We are looking for technical information to tell us the best strategies for siting these radars, and we hope to also get some operational experience at that location, perhaps starting with next year's thunderstorm season.

Mr. GORE. Now the test is going to run through October 1, 1985. Is that correct?

Mr. BLAKE. That's our current plan, yes.

Mr. GORE. Yes, and the start date?

Mr. BLAKE. We have installed virtually all of the equipment at this point in time, and we will be starting to take data next month.

Mr. GORE. Next month? All right, so the equipment has already been installed, and some is south of Memphis, some is east of Memphis, and some is right at the airport itself.

If the test goes as well as we all hope it will, when could we expect to see this kind of equipment used in airport operations on a widespread basis in the rest of the country?

Mr. BLAKE. Well, if we are able to initiate a program, it is not beyond reason to expect to start to see them occurring in the later 1980's time period, early 1990's time period.

Mr. GORE. Now can you give me an estimate on the cost of this test?

Mr. BLAKE. I think we would probably be better to go a little further in our development work and supply that later for the record, if we could.

Mr. GORE. Can you give me a rough idea?

Mr. BLAKE. I can give you a very approximate idea based on some of the preliminary costing from the next generation weather radar system, and that is in the order of—installed costs in the order of $4 or $4 plus million per site.

Mr. GORE. I appreciate that, and we will look forward to the——

Mr. BLAKE. That's a very, very rough estimate.

Mr. GORE. I understand that, and we'll take it with that caution and we'll look forward to the more detailed information for the record.

[The information follows:]

Based on work done to date on the enroute NEXRAD system, we expect the installed cost of a terminal Doppler radar to be in the range of $4M to $5M. However, the program is still in the experimental and developmental stage. System definition activities are currently underway that will result in development of more detailed budget estimates for a terminal Doppler radar program.

The Memphis test activity will involve expenditures of approximately $7.5 million over three fiscal years (fiscal year 1984 through fiscal year 1986). It will make use of the following facilities: 2 Doppler weather radar and associated data processing facilities; a 30-unit Mesonet (Ground Weather Sensors); the Low Level Wind Shear Alert System; 2 instrumented aircraft; 2 laser (LIDAR) devices; NWS weather radar, and FAA surveillance radars and ATC facilities.

I want to thank you for being here and thank you for undertaking this project in the wake of the hearings we conducted 2 years ago. We were critical at that time of the lack of priority being paid to this problem. You have moved. We still have concerns about appointing people in FAA to be in charge of weather problems and having the line of responsibility clarified and other things, but I want to thank you and congratulate you on moving forward with this important project. Again, I'm pleased that it is in Memphis, and I appreciate the chance to see you today.

Thank you, Mr. Chairman.

Mr. CARNEY. Thank you, Mr. Gore.

Mr. Blake, we both will have to go to vote, and instead of asking you to stay as a panelist I would ask that I will have a couple of questions I will submit to you in writing that I would hope you can send back to the committee.

Mr. BLAKE. Fine.

Mr. CARNEY. But before I move to go to vote, I would like to comment on the installation of the LLWAS programs. You did in your testimony mention that you have 59 installed and 51 are on the drawing board. You are keeping with the schedule. It's a very energetic schedule and for that I believe the FAA should be congratulated. You have moved in a very, very rapid fashion.

The one question that I would hope you could answer for us in writing, because indeed I have to go to vote, is the question that was brought up today about the fact that there is a reluctance on

the part of the FAA to have angle-of-attack instruments to assist pilots in maneuvering through the wind shear phenomenon in airline transports. That would be one question. I have a couple of other questions, more technical, and unfortunately I have to run so I will submit those to you in writing, probably have them up to your office before the end of the week, and we would appreciate a response to them. OK?

Mr. BLAKE. We will be happy to answer them, yes.

[The information follows:]

FAA has no objection to the use of angle-of-attack instruments in air carrier aircraft to assist pilots in maneuvering through inadvertent wind shear encounters. However, we believe that use of angle-of-attack information as an input to flight guidance systems incorporating wind shear logic, as opposed to angle-of-attack indicators, provides improved control information that assists the pilot in obtaining maximum performance from the aircraft during the wind shear recovery maneuver. The use of angle-of-attack instruments directly as an aid in wind shear encounter recovery is being examined by such forums as the Airline Transport Association Wind Shear Task Force. One airline company is currently considering implementation of angle-of-attack indicators and is testing this equipment at its flight simulation facility.

Mr. CARNEY. OK. I forgot. I was looking at the wrong schedule here. We do have another panelist. We have Ernst Krubsack and Samuel Saint who will be testifying, and that will happen as soon as I get back from the floor. Thank you.

[A short recess was taken.]

Mr. CARNEY. Our next panel of witnesses consists of Mr. Ernst Krubsack, manager of Market Development and Sales, and Samuel P. Saint, Safe Flight Instrument Corp., from New York. We appreciate the patience that you gentlemen had. It has been a long day. I might note that I have voted three times, and it took me less time to run over to the floor of the House three times and come back here than it takes me to get my baggage from National Airport, so that's a little bit of an improvement.

Gentlemen, please, we will take your testimony and submit it in the record, so if you would like to make a summary of your testimony I think you have a presentation as well. Is that correct?

STATEMENT OF ERNST A.W. KRUBSACK, DIRECTOR OF MARKETING AND SALES, SAFE FLIGHT INSTRUMENT CORP., WHITE PLAINS, NY, ACCOMPANIED BY SAMUEL P. SAINT

Mr. KRUBSACK. Yes, sir, and thank you. I am Ernie Krubsack with Safe Flight, and to summarize it I think I would just like to show you a small film. It takes about 6 minutes and it will probably summarize what is available, and we'll take it from there.

Mr. CARNEY. Fine. Did you bring the popcorn?

Mr. SAINT. No popcorn. [Laughter.]

[A short film was shown.]

Mr. KRUBSACK. Sir, this film was presented as a summary of the wind shear warning system as it existed when this film was produced. However, Safe Flight has produced and developed a flight guidance capability.

Mr. CARNEY. Scott, could we get some lights, please? Thank you. I'm sorry. Thank you.

Mr. KRUBSACK. By all means.

In both the warning and the recovery guidance, Safe Flight has rejected any notion that the pilot could or should monitor or use separate instruments for either warning or recovery. For warning, the cockpit speaker announces, "Wind shear, wind shear, wind shear."

We have judged that computed pitch for recovery guidance must be presented through the flight director command bars, the same instrument that the pilot uses in normal flight operations. We have also realized that the pilot caught in the rapidly changing horizontal and vertical currents of a microburst could not possibly know from normal instrumentation how to program his pitch attitude to get and hold optimum angle of attack in the recovery operation. The pilot attempts to use his experience and training acquired through 1 G flight conditions to solve a rapid and constantly changing set of aerodynamic conditions that confuse not only his own senses but the very instruments he has learned to interpret and trust.

Proof of this point is found in at least three NTSB accident reports. The NTSB has said on these occasions that the pilots were not to blame, but they also reached the seemingly contradictory conclusion that the aircraft had unused performance capability. What this comes down to is a simple and disturbing fact: The pilot, without computed help, had no way of knowing how to determine the pitch attitude required to get the optimum performance out of the aircraft in the escape maneuver.

Recognizing this special requirement for pitch guidance, we have developed and introduced a recovery guidance mode into the flight director system. This escape mode is triggered by the discreet warning of the warning system.

We believe that an airborne warning system must provide the earliest practical warning. The warning must be simple, not requiring instrument interpretation, and it must be self-monitoring. It must also not be susceptible to give false warnings. It must provide computed pitch guidance for recovery to allow use of all the performance capability of the aircraft. The system must provide a profile which would establish a flight path resulting in a minimum loss of altitude and a positive rate of climb as soon as possible. We also agree that this system must be based upon angle of attack.

We understand the benefits in developing and deploying a reliable ground-based advance warning system to give the pilot an earlier warning that could make it possible to avoid recognizable microbursts. The decision to avoid or penetrate a possible wind shear encounter, however, must remain with the pilot in command, as we have continued to preserve the ship captain's authority. The forces acting on an aircraft cannot be assessed by a third party or parties. The eyes and ears of a ground-based observer are only as accurate as the remote sensors. If and when these sensors become available, are we ready to shift the pilot's decisionmaking authority to a ground-based organization? It is also important to consider the time delay factor in relaying this information to the pilot, who must then take action. Are we, as the aviation community, willing to take the disastrous financial responsibility to close a major airport because wind shear is suspected?

We have some further things that we are concerned with, but I would like to turn it over to Mr. Sam Saint, one of our consultants, who will elaborate on some of the pitch guidance information, sir.

Mr. SAINT. Mr. Chairman and the gentlemen that remain, I would like to take about 5 or 6 minutes. Are you getting my——

Mr. CARNEY. We might have a little bit of a problem here. I have been notified by the committee that this committee room has to be vacated almost immediately for a markup scheduled at 2 o'clock, so you are going to have to go very rapidly, sir.

Mr. SAINT. I'll take just 5 minutes, Mr. Chairman.

NTSB, as Mr. Krubsack has told us, raised a very interesting question when in accident investigations they said the pilot was not to blame, but they also said the aircraft had performance capability that was not used, and this raises a very important question: What have we not done for the pilot to make it possible for him to get the maximum performance out of his bird?

I show you this picture of Fujita's and others' analysis, the data coming out of the JAWS project, to make only two points: One, the pilot can be taken completely by surprise; and, two, the duration, the time element that the pilot has to make his decision is extremely short, measured in seconds. There is no time for the pilot to analyze trends or anything else.

Now the vertical component in a shear is an extremely important part of the hazard. The importance of the vertical component has often been played down. I don't know—I suspect you have all seen Fujita's picture of the Andrews microburst—a microburst that hit the Andrews runway only 5 minutes and 15 seconds after Air Force One touched down. Here we have a wind from WNW 20 WNW 130 knots in 80 seconds. The anemometer was solid against the peg. Roofs were coming off buildings. Trees were being uprooted. In the next 100 seconds the wind dropped to 3 knots, and in 90 seconds more was up to 84 knots in the opposite direction—a 180-degree change of wind direction. You have to know that that was a horrendous outflow measured only 35 feet above the ground. The vertical component that was feeding that outflow had to be hitting the ground like a fire hose hitting concrete.

The vertical component just cannot be ignored, so when the pilot hits a microburst and it takes him by surprise, he has to have two things and he has to have them very fast. In the first place, he has to have a warning that makes an absolute, a concrete, a specific measure of the threat that the nose of the airplane is against, and he has to have pitch guidance in the escape maneuver.

To understand the possibility of giving the pilot a computed warning of the hazard that he has got his nose against faster than he can get this information from his own instruments, you might consider the space shuttle. If you visualize the space shuttle, when those space shuttle engines fire, if you could measure the force that those engines are producing you will know where that vehicle will be 5 seconds from now and how fast it will be going. But if you have to watch its movement—you have to watch the air speed going out of bounds, you have to watch the sink rate going out of bounds and then figure back to determine what the force of the outside environment was doing, you have lost those critical seconds.

The safe flight concept measures the actual force that the outside environment is placing on the aircraft, exactly at the moment it develops. The safe flight system does one further thing. It sends a signal to the flight director system to program that system for the escape maneuver.

Now to understand why the pilot needs computed pitch attitude to optimize his performance in the escape maneuver, you have to understand that in the presence of an unknown—a vertical component of unknown force, the normal relationship between pitch attitude, airspeed, and angle of attack have come all unglued. The pilot is faced with a situation that he will face maybe once in his whole career, maybe never. And in that once in a career situation all of his experience and all of his training as to how pitch attitude and airspeed control angle of attack is no longer valid. He must have computed pitch attitude because he cannot know from his normal instrumentations what his pitch attitude should be.

Here is a drawing done by Mark Kirschner, of Boeing Aircraft Co., to show what happens in a shear encounter. To be very brief, look at the three curves on the bottom. The airspeed curve shows the airspeed deteriorating to well below V-ref minus 20—V-reference being the speed that the pilot normally carries on final approach. In this heavy shear encounter Boeing teaches to pull up to the stick shaker angle of attack. And he shows that angle of attack on the middle curve. The angle of attack comes right up to the stick shaker line and then holds straight across on that line, but look how the pitch attitude is changing while the stick shaker angle of attack is being held.

So in this case the pilot pulled up to the stick shaker in spite of the airspeed being at that horrendous, scary, low number, and the pilot lost only 150 feet below the glide slope in 16 seconds.

Now here is a case where Mark Kirschner decides that the pilot, wanting to stop the deterioration of the airspeed, delayed pulling the nose up for just a few seconds. He delayed pulling the nose up and he lost more than twice the altitude. He is now 330 feet below the glide slope in 16 seconds, and when you put those two curves together you will see that the airplane arrived at the "stick shaker" angle of attack in the first instance only 5 seconds sooner than in the second instance. In that 5 seconds of hesitation he more than doubled the loss of altitude.

Bill Melvin has told us to be concerned about the "stick shaker" technique. I share his concern about this because of the rapidly changing relationship of the pitch attitude to the stick shaker. Let me illustrate what the pilot is up against here. You can visualize this by visualizing a pilot in a room, blindfolded, with his hands tied behind his back, and told that he has to find the wall over there with his nose in three seconds. By the way, that wall can be coming toward him. This gives you some idea of what the pilot is up against going for that "stick shaker" high angle of attack. But Boeing is correct. He needs that high angle of attack, but he needs to be led smoothly to that point by a computed pitch guidance system, and that's what we are setting out to give him.

Just one more minute. We'll look at a real world situation. Here is Fujita's picture of the New Orleans microburst. Here is Fujita's analysis of the trajectory of Pan American 759, and we have added

to that picture the point at which the Safe Flight alarm would have gone off. The Safe Flight alarm would have sounded before that airplane reached the top of his trajectory and started downhill, and if the pilot then was given command bar guidance to control the pitch attitude, he would have crossed that tree line 130 feet in the air instead of being in the trees.

I'll show you one more slide and I'm finished. Here we have the airspeed curve and the angle of attack and pitch attitude curves on the bottom, showing that the normal relationships of pitch, speed and angle of attack have moved totally outside the pilot's experience.

That airplane was only airborne for 21 seconds. The critical decision time for Pan American 759 could be measured in 5 or 6 seconds of hesitation, doing the wrong thing, worried about the deterioration of the airspeed, not having any way of knowing what his angle of attack was. If he had had pitch guidance in the recovery mode, he would have walked safely out of there.

I thank you very much, Mr. Chairman, for giving me these few minutes.

[The prepared statement of Mr. Greene, president, Safe Flight Instrument Corp., follows:]

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July 25, 1984

The Honorable Dan Glickman, Chairman, and
Members of the Subcommittee on
Transportation, Aviation and Materials, of
the Committee on Science and Technology,
U S House of Representatives

Gentlemen:

We submit for your use as background and perspective relating to your study of the wind shear problem the following record of research and development accomplished by the Safe Flight Instrument Corporation.

We understand that the primary concern of the Committee is to determine the current status of wind shear detection and consider what possibilities appear to hold future promise of development. We submit this record only for background information. It is our conviction that a careful look at where we are today can be helpful in deciding how future research programs should be directed.

The Safe Flight effort has developed operationally proven, immediately available equipment to reduce the hazard from low altitude wind shear.

One of the key questions before this Committee should be the need to examine the relationship between wind shear warning concepts that promise "advance" warning, as opposed to those system concepts that measure the degree of the "threat" as the aircraft enters the actual shear area.

We face a grave danger if we allow a longer term potential for a theoretical "best" system to prevent us from taking immediately available steps to reduce the threat of wind shear disasters now.

It will be the purpose of our statement, here, to prevent a future "advance warning" possibility from diverting attention away from a "direct threat measuring" capability that is available now. These two concepts should not be allowed to come into an either/or competition.

If we, at Safe Flight, have learned anything in the past eight years of concentrated effort to provide wind shear protection, it is that there is little hope of finding one single solution that negates the need for all others.

At this stage we are convinced that the warning generated by "direct threat measurement" that we provide today will continue to be a valuable safety item, even after a ground and possibly an airborne "advance detection" system becomes available.

Certainly, with all possible approaches to "advance detection" systems being admittedly several years away at best, the immediately available "threat measuring" capability should not be turned aside while 727's are knocking out ILS antennas.

On the other hand, we would agree that it is important that the possibility of giving the pilot a reliable "advance warning" should also be emphasized.

Safe Flight has become a respected participant in most of the wind shear discussions and seminars that have been held in recent years. The record will show that our briefings have included: NTSB, FAA, ICOA, NASA, IATA, ATA, ALPA, FSF, SAE, several corporate jet operators, 11 airlines plus a larger number of domestic and foreign air carriers and several major air frame manufacturers through the S-7 Committee of SAE --- In all of these briefings we have consistently encouraged the development, by any technique; doppler, laser, infrared, or whatever, of an "advance warning" capability.

Safe Flight has addressed itself to the aerodynamic solution of the "direct threat" encounter rather than the longer term possibility of advance warning. We have chosen to concentrate our attention on what could be done to provide the earliest possible reduction of our vulnerability to the wind shear hazard.

We believe we have accomplished this goal to an extent that justifies the careful consideration of the responsible government agencies, as well as the user community.

The Safe Flight Warning System is the only warning system that has been certified by the FAA. The Safe Flight Warning System has been granted Supplemental Type Certificates for operation in B747, B727 and DC9 airline aircraft and seven types of corporate jets. It is flying routinely today in more than fifty airline and corporate jets. After four years in actual operation, there is not a single instance of a false warning.

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United Airlines has performed both simulator and flight evaluations of Safe Flight's system. Eastern Airlines has accomplished a preliminary simulator evaluation, and is planning to perform a flight evaluation. Hawaiian Airlines and KLM Airlines have also accomplished flight evaluations. In addition, the Boeing Commercial Airplane Company has completed its own simulator evaluation. Eastern Airlines and United Airlines have installed and will be evaluating the Safe Flight Warning and Recovery Guidance System in simulators capable of printing out the result of each flight. Republic is planning a similar evaluation. NASA and Safe Flight are considering installation of the Safe Flight System in both the NASA B737 simulator and their B737 test aircraft.

From these simulation trials we can expect to see a solid block of documentation proving the effectivity of the Safe Flight System.

These simulation tools will also insure the development of more effective pilot training for wind shear escape and/or avoidance.

You will be interested now, we think, to look at the list of requirements to which Safe Flight has worked. Consider the following: (We think a somewhat similar set of requirements might be adopted by the Committee to guide research toward a suitable "advance warning" system.)

1. The need to do something that could be accomplished immediately. Existing technology dictates a "threat measuring" capability rather than waiting for the development of an "advance warning" system.

2. A Safe Flight Warning System was flown for two years in a United B727, providing continuous data to a recorder. The data obtained substantiated the optimum level of threat measurement at which to trigger the Warning and immediately switch the Flight Director system into a "recovery guidance" mode.

We wanted a system that was universally applicable -- a system that would work everywhere the aircraft went. This, of course, dictated that the system be carried on the aircraft itself.

3. The menacing nature of the microburst threat (as we long suspected and the JAWS project proved) was such that the pilot could be taken completely by surprise. Since it has been determined that a pilot might see this phenomenon once, if at all, in a long career, the warning had to be so simple and reliable that the pilot could act on it without hesitation.

4. The further study of the microburst threat - as we have found from flight data recorders, from the JAWS project and, most recently, from the Andrews microburst of August 1st, 1983 - has made it abundantly clear that measurement of the energy loss occasioned by the shear, must measure and sum the energy loss from the vertical as well as the horizontal elements of the shear.

The danger from the vertical component of the shear comes from two sources. There is the energy loss from the downdraft, as it pushes the aircraft down. But, the vertical wind does something that may be even worse. The downdraft destroys the normal relationships between the airspeed, pitch attitude and angle of attack. In the presence of a downdraft of unknown force, the normal pitch attitudes and airspeeds used by the pilot during a lifetime of experience and training are no longer valid. It becomes necessary to use an angle of attack based system for guidance.

The vertical component of the shear cannot be ignored.

5. The erratic way in which a microburst suddenly appears from above creates another problem. That problem is the realization of both the occurrence and severity of the encounter, by the pilot. Recognition of a low altitude microburst can occur too late for recovery as we early learned from accident records, and JAWS has since fully documented. These records made it clear to us that a pilot, taken by surprise, will have no time to analyze the "trends" of airspeed, sink rate, or any special instrument. Time and again the accident record shows that 5 or 6 seconds made all the difference between disaster and possible escape. For this reason Safe Flight has gone with an extremely simple warning. A cockpit speaker announces: "Wind Shear! Wind Shear! Wind Shear!".

Furthermore, in both warning and recovery guidance, Safe Flight has rejected any notion that the pilot could, or should monitor, or use separate instruments for either warning, or recovery guidance. It has been judged that commanded pitch for recovery guidance must come from the pitch command bars of the flight director, the instrument the pilot uses all the time in normal aircraft operation.

6. Safe Flight has also realized that the pilot, caught in the rapidly changing horizontal and vertical wind currents of a microburst, could not possibly know, from normal instrumentation, how to program his pitch attitude to get to and hold optimum angle of attack in the recovery operation. The pilot attempts to use his experience and training, acquired during 1G flight conditions to solve a rapid and constantly changing set of aerodynamic conditions that confuse not only his own senses, but also the very instruments he has learned to interpret and trust.

Proof of this point is found in at least 3 NTSB accident reports. NTSB has said on these occasions that the pilots were not to blame. But they also reached the seemingly contradictory conclusion that the aircraft had unused performance capability. What this comes down to is a simple and disturbing fact. The pilot, without computed help, had no way of knowing how to determine the pitch attitude required to get the optimum performance out of the aircraft in the escape maneuver.

Recognizing this special requirement for pitch guidance, Safe Flight has introduced a Recovery Guidance mode into the Flight Director System. This escape mode is triggered by the warning element of the system.

Safe Flight believes an airborne warning system must provide the earliest practical warning. The warning must be simple, not requiring instrument interpretations and self monitoring. It must not be susceptible to give false warnings. It must also provide computed pitch guidance for recovery to allow use of all the performance capability of an aircraft. The system must provide a profile which will establish a flight path resulting in a minimum loss of altitude and a positive rate of climb as soon as possible.

IN SUMMARY WE HAVE REACHED THESE CONCLUSIONS -

1. The Safe Flight Warning and Recovery Guidance System is available now and provides important protection against the hazard of low altitude wind shear.

2. The Safe Flight Wind Shear Warning Computer measures the threat at the entering edge of the problem area and warns the pilot before he can possibly determine from his own instrumentation the degree to which the outside environment has turned hostile. For example, in the New Orleans tragedy, the Safe Flight warning would have been triggered before the aircraft reached the top of its brief trajectory. This flight, had it been following the Safe Flight Recovery Guidance through the command bars of the Flight Director, would have been 130 feet in the air crossing that tree line.

3. We understand the benefits in developing and deploying a reliable, ground based "advance warning" system to give the pilot an earlier warning that could make it possible to avoid recognizable microbursts. The decision to avoid or penetrate a possible wind shear encounter, however, must remain with the pilot in command, as we have continued to preserve the ship captain's authority. The forces acting on an aircraft cannot be assessed by a third party or parties. The eyes and ears of a ground based observer are only as accurate as the remote sensors. If and when these sensors become available, are we ready to shift the pilot's decision making authority to a ground based organization? It is also important to consider the time delay factor in relaying this information/decision to the pilot, who must than take action. Are we, as the aviation community, willing to take the disastrous financial responsibility to close a major airport because wind shear is suspected?

4. The more difficult problem of providing an airborne "advance warning" should also be pursued. We think, however, that successful development of such a system is not likely to be seen before the end of this decade, at the earliest. We submit that the industry cannot risk further wind shear disasters while we wait for an on-board, "advance warning" system.

5. We forsee that the discrete and absolute energy loss measurement provided by the Safe Flight System will continue to be required into the forseeable future even if airborne, or ground based "advance warning" systems were to come into use. It seems clear today that no single solution to the wind shear hazard will provide the overall protection we need. The complex nature of the problem will demand that solutions continue to be pursued on more than one front.

We wish to thank the Committee for the opportunity to put into the record our concerns.

Very truly yours,

SAFE FLIGHT INSTRUMENT CORPORATION

Leonard M. Greene

Leonard M. Greene
President

/jm

Mr. CARNEY. Thank you.

Unfortunately, we are rushed because we have to vacate the committee room. I would ask that you provide for the committee the technical data on the instrumentation, its size, that type of thing, its cost, projected cost for the instrumentation. I would ask a couple of questions, and if you could answer them in kind of like a yes/no fashion, it would be helpful.

One, do you think that the airline transports should have angle-of-attack instruments to assist pilots in maneuvering through the wind shear?

Mr. KRUBSACK. Yes, sir.

Mr. CARNEY. Two, is it true that there are some types of wind shear or microbursts from which a pilot just can't recover at low altitudes?

Mr. KRUBSACK. Yes, sir. We have not yet measured the strongest one to reach the earth, and I'm sure that there is going to be a big one coming sometime. A microburst with an extremely violent downburst can far exceed the performance capabilities of the latest technology transport catagory aircraft.

Mr. CARNEY. And I would suspect, too, it depends upon where the plane is when the microburst occurs. Even a small microburst, if the plane is too close to the ground you would have a problem with the warning. There's just not enough reaction time.

Mr. KRUBSACK. Agreed. The new simulators that are being developed by the FAA and the airlines are taking the microburst phenomenon of various strengths, and have the capability of moving them around on your flight path, and from that data we should be able to substantiate some of our findings.

Mr. CARNEY. Would you agree that the best approach to wind shear would be to avoid them entirely?

Mr. KRUBSACK. Indeed, sir, our statement brings that out: Without a doubt, do not go into it if you know it's there.

Mr. CARNEY. Then quickly there's some questions I have on not so much the warning part of your program but on the reaction part, the collision avoidance or whatever you might want to call it. Are you satisfied with the algorithms used in your recovery guidance system?

Mr. KRUBSACK. Yes, sir. To the best of our knowledge, they provide us with the optimum recovery guidance. There are some questions with other people that they would like to see them refined. However, the philosophy and the techniques we are using are basically agreed upon by all parties. There are some reports by the Boeing Commercial Airplane Co. which will clarify this.

Mr. CARNEY. I could appreciate that. I think the concept and the philosophy would be agreed upon but do we have a model, a data base that makes us confident in the algorithms as far as the makeup of various wind shears?

Mr. KRUBSACK. When you speak of various wind shears, I——

Mr. CARNEY. Well, we'll go from, certainly a wind shear is not a constant.

Mr. KRUBSACK. Yes, sir.

Mr. CARNEY. They are completely different. Right? Do we have enough data base for you to create reaction, the algorithms for reactions? Do you have enough data base to be confident in that?

Mr. KRUBSACK. Well, the aerodynamics of a wing or the angle of attack on a wing are known from the designers and the manufacturers. We are currently involved in several programs of evaluation with the new generation simulators that Mr. Neal Plake spoke of. Safe Flight is involved in a testing program with Eastern Air Lines. We are involved in a testing program with United Air Lines, and we hope soon to be with Republic and NASA. With that, we will be able to document your question, sir.

Mr. CARNEY. OK. A yes/no answer so we can get out of this room. I'm getting looks.

Is your instrument aircraft-specific?

Mr. KRUBSACK. The algorithms for recovery guidance are, yes, because they depend upon the wing. The warning can be put in any aircraft. To answer your question, it's 6 pounds and it's very inexpensive.

Mr. CARNEY. The next thing is, how easy is it to reprogram the computer if you wanted to update the algorithms?

Mr. KRUBSACK. We have that capability. A return to the factory and then a programing of a chip. It's microprocessor-based.

Mr. CARNEY. OK, and you will provide for the committee the specs, the size, the cost, that type of thing?

Mr. KRUBSACK. Yes, sir. I might add, sir, we are certified on a number of aircraft by the FAA.

Mr. CARNEY. Fine. I thank you very much for your patience and for your very informative testimony, and I thank those who have been here through the hearing. I am sure everyone recognizes the importance of trying to find a solution to the problems associated with microbursts and wind shears so we can improve the safety factor of our airspace and put confidence in the people who use air transports throughout the United States. Thank you.

The meeting is adjourned.

Mr. KRUBSACK. Thank you, sir.

Mr. SAINT. Thank you, Mr. Chairman.

[Whereupon, at 1:45 p.m., the subcommittee recessed, to convene at the call of the Chair.]

APPENDIX

Additional Material Submitted for the Record

Air Transport Association ata OF AMERICA

1709 New York Avenue, NW
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August 8, 1984

The Honorable Dan R. Glickman
Chairman, Subcommittee on Transportation,
Aviation and Materials
Committee on Science and Technology
U. S. House of Representatives
Washington, D. C. 20515

Dear Mr. Chairman:

On July 25, 1984 you convened hearings on "Wind Shear Detection Technology". ATA did not testify at this hearing, but we would now like to supplement the record of your hearing with an overview of recent ATA activity on wind shear hazards.

ATA and individual ATA member airlines have supported or participated in numerous studies on the nature of the wind shear phenomenon, forecasting of certain types of wind shear, the most effective ways to detect low altitude wind shear using both airborne and ground based sensors, development of optimum flight procedures and techniques in the event of an inadvertent low altitude wind shear encounter, and development and use of the most advantageous flight guidance and control aids. Many of these activities continue; there is still much to learn.

ATA and member airline representatives served as members of the National Research Council (NRC) "Committee on Low Altitude Wind Shear and its Hazard to Aviation". Prior to the NRC study, representatives from the airline industry were involved in the 1982 Joint Airport Weather Stuly (JAWS) project. More recent activity has included follow-up studies based upon the JAWS findings. An example is the ongoing 40 day trial at Denver Stapleton Airport, providing microburst forecasts and using the ground based sensors installed for the JAWS project to provide near real-time wind shear warnings to pilots. Another example is participation in the workshop sponsored by the National Center for Atmospheric Research (NCAR) on development of updated wind shear models for use in training simulators and certification of airport systems.

ATA has established a Wind Shear Task Force to address issues that require inter-disciplinary consideration; issues that exceed the scope of activity normally dealt with by standing ATA bodies such as the Meteorology Committee,

the Flight Systems Integration Committee, the Training Committee, and the ATC Committee. The expertise of ATA Task Force members is augmented by representation from outside the airline industry. Non-ATA participants include representatives from the Boeing Commercial Airplane Company, Douglas Aircraft Company, FAA, and NASA headquarters. This cross section of experts keeps current with the latest research efforts of other organizations such as NCAR and the NASA Research Centers, primarily Ames and Langley. The Task Force work program has been developed using the conclusions and recommendations in the NRC Report, "Low Altitude Wind Shear and its Hazards to Aviation" as a guide.

The Task Force has focused initially on those actions believed to have the greatest near term benefit in reducing accident potential arising from inadvertent low altitude wind shear encounter. These actions include:

- Provision of improved ground training for flight crews on the nature of wind shear -- especially microbursts -- and on wind shear recognition and the need for avoidance;
- Development of improved wind shear models for incorporation in simulators used for pilot training and evaluation of alternative simulator training scenarios to identify the most effective training methodology;
- Development of optimum flight procedures and techniques to be employed in the event of an inadvertent low altitude wind shear encounter.

An important result of the above activities will be a set of recommended amendments to FAA Advisory Circular 00-50A. This document is thought to be the best vehicle to insure widespread dissemination to airmen of the latest information about the nature of the wind shear threat and recommended pilot actions in the event of an inadvertent encounter. All members of the aviation community agree that avoidance of low altitude wind shear is the primary objective, but that pilots must be prepared to react quickly and correctly in the event of an unexpected encounter.

The Task Force is expected to next direct its attention to the expanded Low Level Wind Shear Alert System (LLWSAS) at Moisant International Airport in New Orleans and the improved information processing algorithms utilized in the computer associated with this installation. Improvements are needed in the message content and format of current LLWSAS warnings transmitted by controllers to pilots. Experience with the expanded LLWSAS at New Orleans should be instructive in this regard and should also pave the way for recommended improvements to existing and planned LLWSAS installations.

Some ATA member airlines are evaluating airborne sensors to detect wind shear and cockpit instrumentation designed to provide additional flight path guidance information in the event of a wind shear encounter. Task Force members will closely monitor these programs and develop appropriate recommendations.

Over the longer term it is clear that the ground based doppler radar will provide the best means of detecting severe weather phenomena, including wind shear. The airlines strongly support development and installation of the Next Generation Weather Radar (NEXRAD). However, NEXRAD will, for the most part, be dedicated to detection of hazards associated with the enroute portion of flight. Separate terminal doppler radars will be required to provide timely warnings of low altitude wind shear in the vicinity of airports. Airlines look forward to the planned tests of a dedicated terminal doppler radar at Memphis and other locations. Assuming that both versions of the doppler radar prove technically adequate, much work remains to be done to insure that the extraordinary amount of data generated by doppler radar is processed so that the result is a simple, operationally relevant message that can be transmitted to the pilot with a minimum of delay.

We hope that this report has provided a useful overview of the ATA activities that will serve as a supplement to your July 25 hearing record.

Sincerely,

William J. Burhop

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Senior Vice President
Government Affairs

METEOROLOGY

SOLVING THE MYSTERY OF WIND SHEAR

Recently identified phenomena called microbursts may explain the New Orleans air disaster—and many others

by KEVIN McKEAN

Outside, the wipers beat furiously at the windshield. Ahead, the concrete and asphalt of Runway 10 stretched away to a tree line overtopped by thunderheads. Sitting in the cockpit of an idling Pan American World Airways jet, pilot Kenneth McCullers radioed the New Orleans International Airport tower for a weather update. The controller replied that there was a wind shear alert for the airport. A weather front was moving through, he said, adding, "We're right in the middle of everything."

Moments later, the Boeing 727 roared down the runway toward a brief flight and a fiery crash that killed all 145 persons on board and eight others on the ground. The July 9 catastrophe was the second-worst single-plane accident in U.S. history, surpassed only by the 1979 DC-10 disaster in Chicago.

The accident was doubly tragic because it came just as scientists are reaching a new understanding of the mysterious weather condition—wind shear—that probably caused it. A wind shear is a sudden local shift in wind direction or speed, a phenomenon familiar to most pilots, and one that poses a threat to aircraft at low altitudes; during the past decade, it has downed at least seven U.S. airliners. The Federal Aviation Administration has spent close to $12 million since 1979 installing ground-based wind shear warning systems at 58 airports, including New Orleans, and until recently many experts thought the problem might be licked. Now it appears that those warning devices may not be enough.

Wind shear is hazardous to aircraft because it temporarily changes the speed of air flowing over the wings, which in turn changes the amount of lift the wings provide. When a plane flies into a strong, unexpected headwind, the added lift may send it soaring upward like a leaf in a gale. Conversely, when a pilot is unprepared for a tailwind, it can cause the plane to drop.

At high altitudes, flying through a wind shear usually does little more than upset a few drinks and stomachs. But on take-offs and landings, wind shear can be deadly: an abrupt tailwind, which would have reduced lift, may have forced the Pan Am plane down into trees that damaged its left wing and sent it cartwheeling into the New Orleans suburb of Kenner. According to Jim Danaher, of the National Transportation Safety Board, the federal agency that looks into air crashes (DISCOVER, April 1982), investigators arrived at the wind shear hypothesis "by process of elimination" as other possible causes, such as lightning or engine failure, were deemed unlikely.

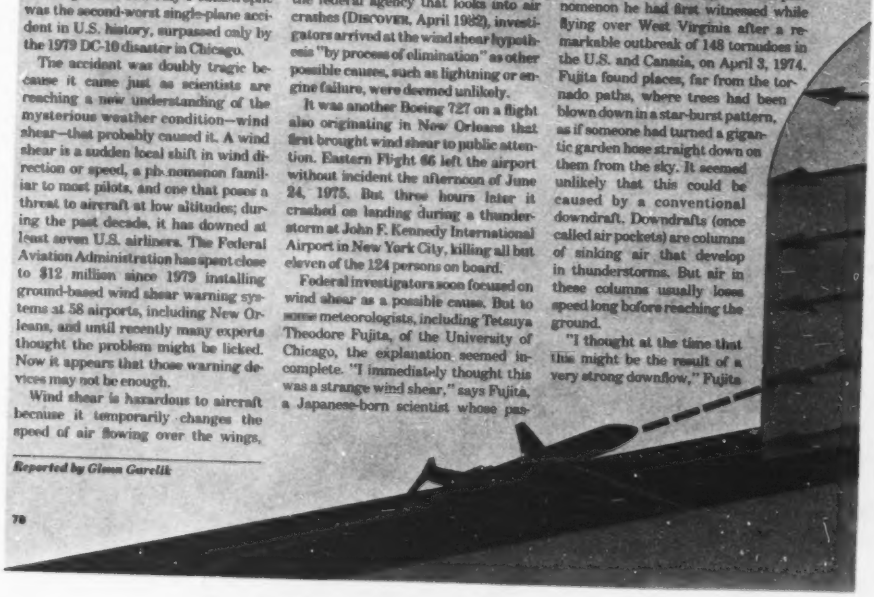
It was another Boeing 727 on a flight also originating in New Orleans that first brought wind shear to public attention. Eastern Flight 66 left the airport without incident the afternoon of June 24, 1975. But three hours later it crashed on landing during a thunderstorm at John F. Kennedy International Airport in New York City, killing all but eleven of the 124 persons on board.

Federal investigators soon focused on wind shear as a possible cause. But to some meteorologists, including Tetsuya Theodore Fujita, of the University of Chicago, the explanation seemed incomplete. "I immediately thought this was a strange wind shear," says Fujita, a Japanese-born scientist whose passionate interest in violent weather has earned him the nickname Mr. Tornado (DISCOVER, May 1981). Fujita was puzzled that only six of the eleven aircraft that landed before the Eastern plane encountered wind shear, and that each met strikingly different conditions.

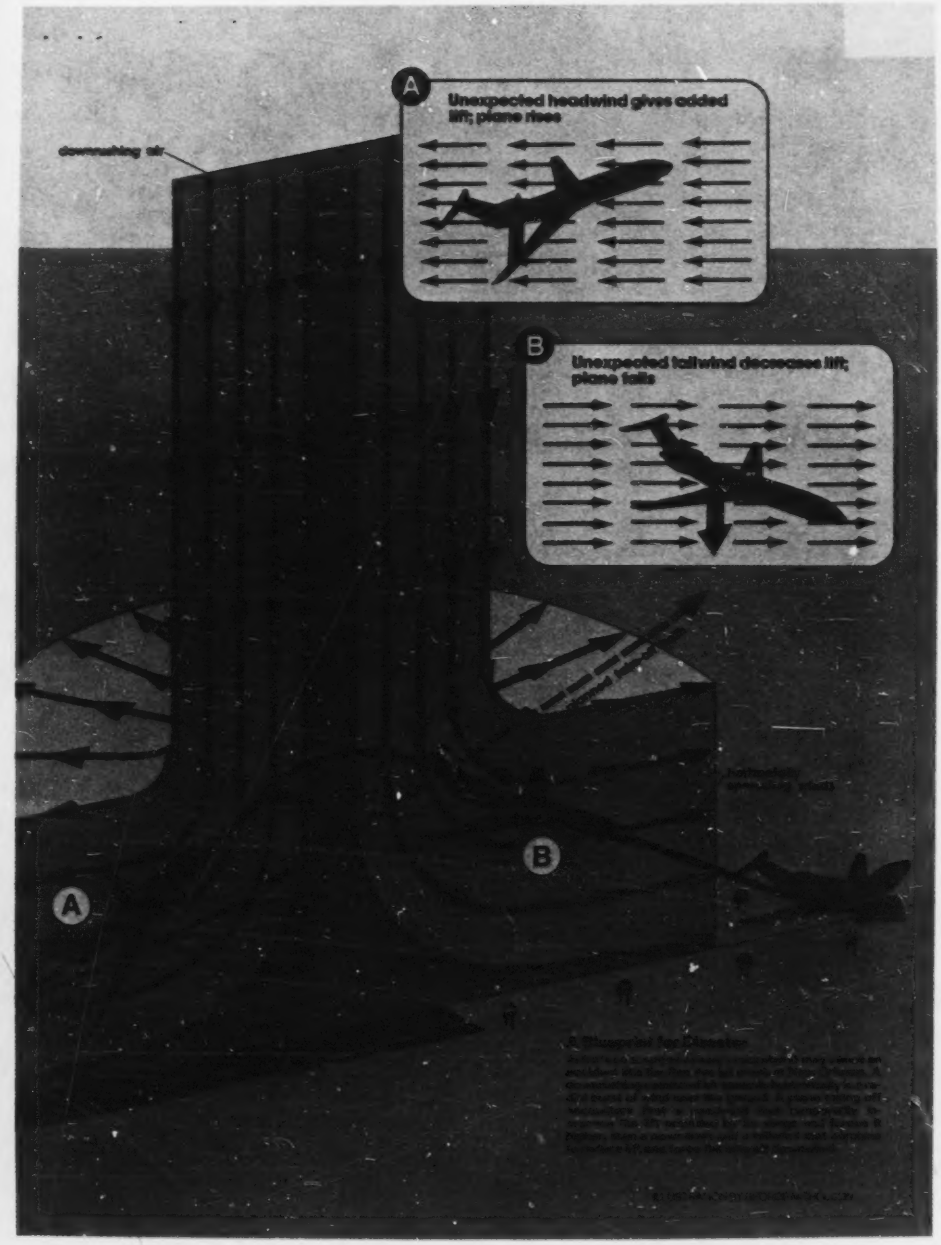
At the time, wind shear was thought to be caused by something called a gust front, a broad band of blustery winds that sometimes precedes a squall line. But a gust front should have affected all planes at Kennedy more or less equally. Instead, the windstorm had downed a 70-ton airliner while scarcely ruffling an airport weather gauge a mile away.

Poring over the crash reports, Fujita was reminded of a strange weather phenomenon he had first witnessed while flying over West Virginia after a remarkable outbreak of 148 tornadoes in the U.S. and Canada, on April 3, 1974. Fujita found places, far from the tornado paths, where trees had been blown down in a star-burst pattern, as if someone had turned a gigantic garden hose straight down on them from the sky. It seemed unlikely that this could be caused by a conventional downdraft. Downdrafts (once called air pockets) are columns of sinking air that develop in thunderstorms. But air in these columns usually loses speed long before reaching the ground.

"I thought at the time that this might be the result of a very strong downflow," Fujita



Reported by Glenn Garelik


A
Unexpected headwind gives added lift; plane rises
downrushing air
B
Unexpected tailwind decreases lift; plane falls
A
B

says, "but until the JFK accident, I couldn't believe it." After the Eastern crash, however, and a similar wind shear accident at Denver six weeks later, Fujita was ready to give the phenomenon a name: downburst, a downdraft with speeds of up to 60 miles per hour that hits the ground and then spreads horizontally in a radial burst of wind.

The JFK accident, Fujita showed, could have been caused by a series of downbursts bombarding the approach to the runway. Planes that landed between downbursts would have been unaffected. But the unlucky jet that flew into the center of one first encountered a headwind that caused the plane to rise, possibly requiring the pilot to throttle back his engines to avoid overshooting the runway. Then the aircraft passed through the opposite edge of the downburst, flying into a tailwind that sharply reduced the airflow over its wings and sent the plane plummeting. (Although the downdraft contributes to the downward push, it is the tailwind that is the greater threat, because the loss of air speed may cause the plane to stall—see diagram, page 79.)

Some pilots landing at Kennedy that day managed to fly out of the tailwind by yanking their planes' noses up and pouring on speed. But jet engines have a six-to-eight-second "spool-up" delay before reaching full power, and the Eastern plane crashed 2,400 feet short of the runway.

Despite Fujita's arguments, many meteorologists were skeptical that downbursts existed. These doubts were silenced when, in a 1978 study near Chicago, Fujita identified as many as ten of them—including one that kicked up 70-mile-an-hour gusts as it spread horizontally only 50 to 100 feet above the ground. "To my surprise," he says, "this downburst had a diameter of only two miles—a size that could fit into an airport." To emphasize how small the phenomenon was, Fujita coined a new term—microburst—for downbursts less than two and a half miles across.

The discovery of microbursts was made possible by a relatively new device, Doppler radar, which can depict winds on a radar screen. Based on the familiar Doppler effect (which causes the whistle of a train to sound higher in pitch as it approaches, and lower after the train passes), Doppler radar measures the rise or fall in frequency of a radar echo to indicate whether the object that reflected it is moving toward or away from the antenna.

Circle marks center of microburst on Doppler screen; bottom, radar dome

While Fujita was studying microbursts, James Wilson and his colleagues at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, were perfecting the use of Doppler radar in weather studies; radar echoes—from raindrops, snowflakes, even dust particles and insects in the air—reveal the speed and direction of the surrounding winds. The results are displayed on a screen in a pattern that is color-coded

by computer to represent wind direction and speed. A microburst makes a distinct pattern: on the screen there is an area of cool colors (blues and greens) for winds blowing toward the radar station; an area of warm shades (yellows, oranges, and reds) for winds blowing away; and, separating the two, an irregular trough of neutral white for winds blowing in a sideways direction, neither toward nor away from the radar antenna (see picture, page 80).

As Wilson focused on detecting microbursts, one of his NCAR colleagues, John McCarthy, was studying how aircraft respond to them. A jetliner in flight, like a tuning fork, will oscillate if perturbed at just the right frequency. McCarthy and his co-workers calculate that for a jetliner trimmed for landing, this resonant frequency is about one cycle every 35 seconds—meaning that headwinds and tailwinds that alternate in a 35-second cycle might yank a plane out of its flight path. By an unfortunate coincidence, the time it takes to fly through an average microburst is roughly 35 seconds. "It so happens that the atmosphere can kick you at just the right frequency," says McCarthy, causing the plane's nose to pitch up and down on a roller coaster ride to the ground. McCarthy, himself a pilot, says that this problem can be handled if it is expected. But if it comes as a surprise, it can contribute to a tragedy.

This summer, the parallel research efforts of Fujita, Wilson, and McCarthy came together in a definitive study of microbursts known as the Joint Airport Weather Studies (JAWS) project. Financed mainly by the National Science Foundation, JAWS is a $2.2 million venture of NCAR, the University of Chicago, and more than a dozen other groups. The data were gathered over a 5,000-square-mile area outside Denver, including Stapleton International Airport, the nation's fifth-busiest field.

The JAWS acronym was aptly chosen, says McCarthy, because "microbursts are lurking insidiously out there, like sharks offshore." From a headquarters code-named Landshark, the scientists commanded a weather network that included three Doppler radar stations, two Doppler lidars (radars that use laser beams), 48 ground-based instrument stations, and six instrumented aircraft, including a high-flying U-2 spy plane. By late July, this far-flung net had caught many fish: nearly 50 microbursts, including 25 (one of which forced Stapleton to close) on July 14 and 15 alone. "We've gotten an incredible abundance of data," says McCarthy. "In all my years as a scientist, I've never seen a program produce so much."

The scientists were surprised to discover that microbursts often last no more than a couple of minutes—a time span the scientists can deal with by providing "nowcasts" of minute-by-minute wind conditions to air controllers.

Another surprising finding was that the darkest thunderclouds do not always hide the most dangerous microbursts. Rather, the chief culprit—at least in Denver—seems to be an ethereally beautiful weather phenomenon called virga (pronounced VER-gah), in which a misty veil of rain falling from a cloud evaporates before it reaches the ground. The evaporation cools the air, so that it plunges downward through the warmer, lighter air below. But, says Fujita, "We might find that dry areas, like Denver, have one type, while wet areas, like New Orleans, Atlanta, and Chicago, have another."

The JAWS project showed that a ground-based network of anemometers (wind gauges), like the Low Level Wind Shear Alert System at New Orleans, is inadequate to warn of microbursts. The gauges might miss microburst winds that are too local or too far aloft. Or if they do detect wind shear, as was the case in New Orleans, their confusing readings might not give a clear picture of where the danger lies. As a result, the JAWS scientists tested five alternative systems, including a British airborne Doppler lidar that gives three seconds' warning—perhaps just enough to avert disaster.

Still, the scientists doubt that airborne radar alone will be enough to cope with microbursts, which they think may cause the majority of wind shear accidents. The day is coming, they hope, when every major airport will have a Doppler radar operator who can close the field if a microburst looms. "All they would have to do is hold for a few minutes, maybe ten times a year," says Fujita. These infrequent delays would be a small price to pay for reducing the hazard of wind shear. ▣